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Macroscopic Traffic Flow Modeling (Case Study In Bahir dar city at Selected Road Segments), Bahir dar, Ethiopia

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ABSTRACT

The goal of this paper is to explore the characteristics of road segments by developing a model that will enable scientifically descriptive estimator of macroscopic traffic flow parameters and the relationship between them (namely, speed, volume and density) in road segments of Bahir Dar city. Also, the research aims to analyze the segments level of service and capacity. Method used for the study segments include, geometric data collection by using field measure and traffic flow parameters collected by using video recording. The parameters are used to develop diagram and mathematical model in each segment and cumulative functions parameters of Bahir Dar city. The analysis model conducted by using three conventional models of Greenshield's, Greenberg's and Underwood's different speed-density models were developed and the best model for each segment and for the city is selected. Level of service analysis is computed by using travel speed of vehicles as a criteria and capacity analysis is done by using volume to capacity ratio. The study result shows that Greenberg relationship represents the flow condition from Giorgis to Gebya and from Zmammeshe building to Mesgid and Gebya to NOC represent by Underwood's model as well. Also, the performance of road segments is poor, since level of service of road is operating under LOS D and the saturation level of two segments is below saturation and one segment operating at saturation level. There must be a measure by installing pedestrian over pass, minimizing number of bajaj and avoiding on street parking on traffic lane.

Keywords: Level of Service, Traffic Flow, Capacity Analysis, Speed Density Model, Road Segments.

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1. INTRODUCTION

Traffic state estimators such as speed, density and flow are important for a number of applications in traffic management and

planning, such as signal timing, determining the number of lanes in highway design, assessing the performance measure of the road, etc. Transportation

macroscopic modeling is a tool for analyzing and prioritizing future transportation improvements. Transportation forecasting and modeling techniques continue to evolve with improvements to computer processing speeds and traffic data collection system. These improvements allow transportation models to be calibrated to real life traffic conditions. The better the model is calibrated the more capable it is to analyze changes to transportation infrastructure.

Traffic flow models have developed over nearly seven decades of research and application; these models can be broadly categorized into microscopic, macroscopic, and mesoscopic in terms of level of detail and process representation. Microscopic traffic flow models provide a detailed representation of individual driver behavior processes in situations such as car-following, lane changing and gap acceptance. As such, these models seek to represent the traffic flow process by describing the behavior of the entities that make up the traffic stream as well as their interactions in detail. This makes microscopic traffic flow models suitable for evaluation of complicated traffic operations under fine-grained representation of road geometries, but usually only for a small network due to their intensive computational requirements [1].

On the other hand, macroscopic traffic flow models, such as the LWR model describe the traffic state at a certain level of aggregation as volume (density, or speed) without considering its constituent particles. The lower level of detail not only reduces the computational burden but also facilitates model calibration [2].

It is important to note in this regard that the success of macroscopic models of traffic derives from the well-documented existence of so-called —collective effects—, resulting from the complex, generally nonlinear, interaction of individual particles in the traffic stream. These collective effects result in relatively simple relations between averages that describe the traffic state, which have proven to be considerably more robust than individual-level microscopic models. Mesoscopic traffic flow models at an intermediate level of detail, describe traffic flow dynamics in aggregated forms but distinguish driver behavior individually [3].

Thus, traffic operations on roadways can be improved by field research and field experiments of real-life traffic flow. Due to the complexity of the traffic flow system, analytical approaches may not

provide the desired results. Therefore, models designed to characterize the behavior of the complex traffic flow system have become an essential tool in analysis and experimentation [4].

For analysis purposes, roadway facilities are separated into categories that are specific to traffic flow type: Uninterrupted and Interrupted traffic flow. Uninterrupted flow in which freeways where there are no intersection at grade, no stop and yield signs, etc. rural high ways and some urban road [5].

Interrupted flow the flow of vehicle in which there is an interruption for the continuous vehicles movement either Recurring (regular occurrences) or nonrecurring (irregular occurrences) interruptions. So this study will depend on interrupted flow since the nonrecurring interruptions occur in the selected road segments (pedestrian crossing, parking, loading and unloading).

This study addresses the specific traffic challenges in Bahir Dar because of rapid urbanization as a center of Amhara Regional government having 554km far from nearest wide and developed city Addis Ababa there is a high migration of peoples to the city in near period and limited road infrastructure, which haven't been well-studied before.

Traffic congestion costs commuters in terms of fuel, extra time to commute the journey and anxiety due to extended delays to arrive at the destination. Traffic congestion also impacts on the economy and society by additional consumption of fuel and by affecting the air quality. Estimates based on INRIX traffic data that congestion on the US roads cost \$121 billion due to delays and additional fuel consumption in the year 2011. The extra time spent by a commuter increased from 16 hours in 1982 to 38 hours in 2011, amounting to 5.5 billion extra hours spent on roads in 2011. Approximately 37% of the total delay is experienced outside the peak hour and day-to-day variation in travel time triggers commuters to plan their journeys for important appointments with extra time [6].

The study reports that the cost of traffic congestion to London's economy in 2013 was \$8.5 billion and it is estimated to increase to \$14.5 billion in 2030. The total cost of congestion to the UK economy in 2013 was \$20.5 billion dollar with \$2,230 per car commuting household. With the current trend of increase in traffic congestion, the future forecasts are alarming and need appropriate measures to tackle this problem [7].

It is important to note in this regard that the success of macroscopic models of traffic derives from the well-documented existence of so-called “collective effects”, resulting from the complex, generally nonlinear, interaction of individual particles in the traffic stream. These collective effects result in relatively simple relations between averages that describe the traffic state, which have proven to be considerably more robust than individual-level microscopic models. Mesoscopic traffic flow models at an intermediate level of detail, describe traffic flow dynamics in aggregated forms but distinguish driver behavior individually [8,9].

from the 1920's through 1950's, several researchers attempted to model these new phenomena. Based on these initial traffic models, new research field emerged and continues to this day [10].

Each decade was dominated by a certain modeling approach The 90ies were dominated by discrete cellular automata models of vehicle traffic and by the systematic investigations of the dynamic solutions of the models developed in the previous 50 years [11].

The microscopic models are useful for the evaluation of effects of new traffic control measures or for predicting the development of the traffic flow in the possible scenarios whereas The macroscopic traffic flow models are suitable for the description of

current traffic states with real traffic data, which is the objective of this research. Therefore, in this research the macroscopic traffic flow models are investigated in depth and applied [12].

There are basically two types of flow interruptions: Recurring and nonrecurring (irregular occurrences) interruptions. The recurring interruptions are the ones fixed to the infrastructure such as: intersection control and lateral clearance issues (fixed road side frictions). Whereas, the non-recurrent interruptions are due to: certain driver behaviors, impeding pedestrian movements, non-fixed road side frictions traffic accidents, disabled vehicles, natural causes such as adverse weather conditions, and spilled loads and hazardous materials [13].

As part of an effort to estimate operating speeds on managed lanes as a function of predicted demands, speed-density models were calibrated using data at a segment site. Many different speed-density models are available including three conventional models of Greenshields, Greenberg and Underwood and the detail is shown below [14]. The set of linear equations for estimating free flow speed in uninterrupted flow system elements based upon data gathered on mean speed, and the posted speed limit; the relationship of 85th percentile speed, and mean speed to posted speed limit from data developed [15].

2. METHODOLOGY

A traffic stream that operates free from the influence of such traffic control devices as traffic signals and stop signs is classified as uninterrupted flow. This type of traffic flow is influenced primarily by roadway characteristics and the interactions of the vehicles in the traffic stream. Freeways, multilane highways, and two-lane highways often operate under uninterrupted flow conditions. Traffic flow modeling is used to show the characteristics flow of vehicles and road condition and this study try to model the flow of vehicles in Bahir Dar city of selected road segments. In this study the great challenge was the consistence of data collection, to overcome this problem it is better to use video camera for count number of vehicle that pass a point in selected segment which is one of the parameter in modeling traffic flow namely flow is collected in the 15 minute of traffic count interval and converted to passenger car per hour, the second parameter is speed of vehicles which is space mean speed calculated as

the length of the road segment divided by the average time spent for sample of vehicles to finish the segment's journey by taking representative sample of vehicles and finally density of the selected road segment is calculated as flow recorded for 15 minute divided by space mean speed of vehicle for 15 minute. Based on the above three parameters speed-density graph, which gives best fit curve in mathematical formula were drawn using MS-Excel by the means of the most known and conventional models of Greenshield, Greenberg and Underwood Models, also the parametric value mentioned. After all the capacity and level of service of the road segments is evaluated.

2.1. Urban street class
2.1.1 Free-Flow Speed

The free-flow speed is used to determine the urban street class and to estimate the segment running time. If FFS cannot be measured in the field, the analyst should attempt to take measurements on a similar facility in the same area or should resort to established local policies. Lacking any of these options, the analyst might rely on the posted speed limit (or some value around that limit) or on default values HCM. Free-flow speed on an urban street is the speed that a vehicle travels under low volume

conditions when all the signals on the urban street are green for the entire trip. Thus, all delay at signalized intersections, even under low flow conditions, is excluded from the computation of urban street FFS. The best location to measure urban street FFS is midblock and as far as possible from the nearest signalized or stop-controlled intersection. This measurement should be made under low flow conditions (less than 200 veh/h/lane).

Table 1. Default free flow speed by urban street class for use in the absence of local data

Urban street class	Default (mi/h)
I	50
II	40
III	35
IV	30

Since measuring free flow speed is very difficult in the field, I can take the design speed value of ERA geometric design manual for urban road and DC8

road (Bahir Dar city roads) that is 50 km/hr or 28mi/hr which falls under urban street class IV having FFS of 30 mi/hr and below [\[16,17\]](#).

2.1.2. Data Collection interval

According to Highway capacity manual for peak hour factor, traffic flow analysis and capacity analysis, level of service analysis, standard data aggregate period for volume, speed & density measurement uses 15-minute period count interval

standards so that I used 15-minute intervals because it offers a good balance between capturing detailed traffic patterns and keeping the data manageable for analysis.

2.2. Passenger car unit

Passenger Car Unit (PCU) is the metric used to convert heterogenic traffic in to homogenous traffic. Passenger Car Unit or Passenger Car Equivalent is first introduced by Highway Capacity Manual In 1965. PCU defined as in Highway Capacity Manual is “The number of passenger cars displaced in the traffic flow by a truck or a bus, under the prevailing roadway and traffic conditions”. This definition of PCE was for relative homogeneous traffic conditions prevailing in developed countries. This calculation is relevant to capacity and level of service determination, lane requirements, and determining the effect of traffic on highway operations. The most recent Highway Capacity Manual 2000 reports PCEs for basic freeway segments according to percent and length of grade and proportion of heavy vehicles.

Passenger car units are used to represent the effects of varying mixed vehicle types on traffic stream. The traffic volume data of road segment is important for operational analysis for that roadway system. Traffic on congested highways is of the mixed nature to assess the different types of vehicles on highways. This study of passenger car equivalency is concerned with determining of the PCU values of vehicles that convert mixed nature traffic flow at on selected congested highways or intersection to the same vehicle type. PCU is the different types of vehicles offer different degree of interference to the other traffic it necessary to bring all types to a common unit. The common unit adopted is expressing the volume as Passenger Car Unit (PCU) per hour (5). In this study analysis of traffic flow modeling passenger car equivalency of mixed traffic that

occurs in Bahir Dar city will be converted to homogenous traffic by combining both The Indian Roads Congress (IRC 106-1990) code and Ethiopian Road Authority (ERA) manual of 2013, also the type

of vehicles and its composition in the research area where indicated and specified in the table below [18,19].

Table 2. Passenger car unit used in the study (adapted on IRC 106-1990 and ERA, 2013)

Vehicle type	PCU factor		Adapted from
	Having vehicle composition of		
	0-10%	10% and above	
Hand cart	2	3	IRC 106-1990
Tonga (horse drawn vehicle)	1.5	2	IRC 106-1990
Wheel chair	0.7	0.7	ERA, 2013
Bicycle	0.4	0.5	IRC 106-1990
Motor cycle	0.5	0.75	IRC 106-1990
Bajaj	0.4	0.4	ERA, 2013
Passenger car and minibus	1	1	IRC 106-1990
Light Commercial vehicles (LCV) and small bus	1.4	2	IRC 106-1990
Large bus/truck	2.2	3.7	IRC 106-1990
Truck trailer	4	5	IRC 106-1990

2.3. Data collection methodology

In one of traffic engineering discipline namely traffic flow modeling of urban road there is two basic data needed to start modeling after selecting segments of road that is traffic data and geometric data. In traffic data collection the basic flow parameters and vehicular characteristics as a whole is studied and in geometric data collection the geometry of road way infrastructure is studied.

In this study to collect the basic flow parameter i.e. speed, flow and density so for accurate and reliable data collection better to use video camera recorder and the three parameters were taken from video

recorder and the procedure is shown in traffic data collection section below. The data collection segments location, date and hour is determined by distributing 50 questioners for road users. According to the result data collection taken from; Gebaya to NOC (Keble 14) segment is by Thursday November 2/2017, Zmamneshe building to Mesgid (Keble 4) segment is conducted by Friday November 3/2017, Giorgis to Gebeya segment were collected by Saturday November 4/2017.

2.3.1. Segment selection

The road segment selection criteria is that the modeling must studied in order of the selected segments is vulnerable to congested and also hour of a day in which three of prior congested segment where subjected to both congested and free flow state. In segments selection it is better to develop

questioners to distribute for users of the roads so that the selection that in the study used is fair selection, there for my study used both field observation (50%) and questioners (50%) as road segment selection criteria.

Table 3. Summery result of respondents' profile

Respondents question	Respondents type	Frequency	Percent
Sex	Male	43	86%
	Female	7	14%
Age	20-30	27	54%
	30-40	23	46%
How long have you been live in Bahir Dar city?	Less than 2 year	5	10%
	3-5 years	23	46%
	5-8 years	16	32%
	>8 years	6	12%
Frequency that respondent use vehicle transportation system	Hard frequent	39	78%
	Some frequent	10	20%
	Some times	1	2%
Type of transportation system respondent use	Public bus	3	6%
	Taxi	41	82%
	Owned or company car	6	12%
Which type of road user are u?	Public servant road user	35	70%
	Business man	10	20%
	Driver	5	10%

The table below summarize the field observation and questioners result, also field observation is done and the value of traffic share is assigned considering if 100% traffic is on total sum of the five segment listed

in table below, after all the average of Questioners and field observation where taken as selection value of the segments.

Table 4. Summary of result from questioners and field observation for congested segment and day selection

Segment selection criteria		Main segments of Bahir Dar city that vehicular traffic share is high					
		Gebya to NOC	Kebel 13 to Giorgis	Giorgis to Gebeya	Zmammeshe building to Mesgid	Polytechnic university to Giorgis	Papyras hotel to Peda
Number of questioners		50					
Frequency (rank 1 up to 3)		9	5	12	10	5	9
Percent		18%	10%	24%	20%	10%	18%
Own field observation		19.5%	14.0%	21.0%	18.0%	12.0%	15.5%
Total percentage		37.5%	24.0%	45.0%	38.0%	22.0%	33.5%
Day of a week congestion occur	Saturday	37%	53%	52%	49%	54%	48%
	Throughout the week	67%	57%	48%	51%	46%	52%
Hour of a day (congested + uncongested) occur	From 9:00-12:00 A.M	61%	64%	69%	65%	63%	60%
	From 4:00-7:00 P.M	39%	36%	31%	35%	37%	40%
Priority on congestion		3	5	1	2	6	4

From the above table to summarize the congestion state of the Bahir Dar city road segment occurs at three main roads segments namely Giorgis to Gebeya, Gebeya to NOC (Keble 14) and Zmamneshe

2.3.2. Geometric data collection

The data with regard to Geometric data category are as per Functional Classification.

Lane (width, number, utilization etc.),

Dimension (segment length, intersection sizes),

Median (type, width), Walkway (width, utilization) and

Intersection (type, class, and channelization).

Main road of Bahir Dar city was constructed by CRBC (China Road and Bridge Corporation) and according to the company data the number of lane

building to Mesgid (Keble 4) segments also the selected hour for analysis period is from 9:00 A.M to 12:00 A.M.

available for traffic flow is 3 lane and only for public city bus station added one additional lane for loading and unloading of bus users, there for number of lane used for vehicle traffic flow is 3 lane which would use for analysis process. Also after collecting the data on numbers of lane from design and from persons who performs the construction, measurement using tape meter is conducted on each segments to have the exact segment width, lane width and number of lane.

Table 5. Summary of geometric data for all three segments

Segments	Data collected segment length (m)	Type of carriage way	Segment width (m)	Lane width (m)	Number of lane
Gebya to NOC (Keble 14)	69.3	3-lane (one way divided)	10.5	3.5	3
Giorgis to Gebeya	53.55	3-lane (one way divided)	10.5	3.5	3
Zmamneshe building to Mesgid (Keble 4)	66.5	3-lane (one way)	9.5	3.2	3



Figure 1. data collection segments and points

2.3.3. Traffic data collection

2.3.3.1. Speed

The average speed is an important property of the traffic situation because it relates to safety, time, comfort and convenience. In traffic engineering, speed is defined as the distance travelled by a vehicle over a certain period of time. It is expressed as distance per unit of time or kilometer per hour.

Space mean speed is determined on the basis of the time necessary for a vehicle to travel some known length of roadway. It account for both the segment length and travel time of that road section, and is computed by dividing the segment length by the mean or average travel time of a group of vehicle [5].

$u_s \text{ Avg.} = \frac{l}{t_{\text{avg}}}$ and $t_{\text{avg}} = \frac{1}{n} \sum_{i=1}^n t_i$ which combining gives $u_s \text{ avg} = \frac{l}{\frac{1}{n} \sum_{i=1}^n t_i}$

Where: - $u_s \text{ Avg.}$ = space-mean speed in unit distance per unit time.

l = length of roadway used for travel time measurement of vehicles.

t_{avg} = average vehicle travel time.

t_i = time necessary for vehicle to travel a roadway section of length l and.

n = number of measured vehicle travel time. Since calculating the speed of every vehicle passing all in 15 minute if difficult this study uses according to travel time data collection handbook. The speed of vehicles as per the below shown tables, for the sake of simplicity in order to minimize the sample size [20].

According to this book, Sample Size n is expressed as,

$$n = \left(\frac{t \cdot s}{\epsilon} \right)^2 \dots \dots \dots (1)$$

Where: t = t-statistic from Student's t distribution for specified confidence level;

s = standard deviation of travel time; and

ϵ = maximum specified allowable error.

$$\text{Coefficient of Variation, c.v.} = \frac{s}{\bar{x}} \dots \dots \dots (2)$$

$$\text{Relative Error } e = \frac{\epsilon}{\bar{x}} \dots \dots \dots (3)$$

Where $\bar{x}$ = mean travel time.

Substituting 2 and 3 in to 1 sampling size

$$n = \left(\frac{t \cdot (c.v \cdot \bar{x})}{(e \cdot \bar{x})} \right)^2 = \left(\frac{t \cdot c.v}{e} \right)^2 \dots \dots \dots (4)$$

Table 6. Coefficients of Variation for the Test Vehicle Technique on Freeways and Arterial Streets

Freeway road		Arterial road	
Average Daily traffic (ADT) volume per lane	Average Coefficient of variation	Traffic Signal Density (signals per database)	Average Coefficient of variation
Less than 15,000	9	Less than 3	9
15,000 to 20,000	11	3 to 6	12
Greater than 20,000	17	Greater than 6	15

Table 7. Illustrative Test Vehicle Sample Sizes on Freeways

		Sample size (from iteration of equation 4)		
Average Daily traffic (ADT) volume per lane	Average Coefficient of variation	90% Confidence, ± 10 % Error	95% Confidence, ± 5 % Error	97.5% Confidence, 2.5 % Error
Less than 15,000	9	5	6	15
15,000 to 20,000	11	6	8	21
>20,000	17	10	14	47

Table 8. Illustrative Test Vehicle Sample Sizes on arterial road

		Sample size (from iteration of equation 4)		
Traffic Signal Density (signals per database)	Average Coefficient of variation	90% Confidence, $\pm 10\%$ Error	95% Confidence, $\pm 5\%$ Error	97.5% Confidence, 2.5 % Error
Less than 3	9	5	6	15
From 3 to 6	12	6	8	25
Greater than 6	15	9	12	37

In this study analysis the road classification of Bahir Dar city is under arterial road having less than 3 signals in the whole city and chooses to perform study analysis on 95% Confidence interval. So the sample of vehicle needed for analysis of travel speed and modeling of traffic flow is 6 vehicles for every 30 minute interval.

This study chooses 10 sample vehicles in every 15 minute for average travel speed calculation, since increasing in sample vehicle will make more reliable

data. The table below shows typical value used for Analysis of segment from Giorgis to Gebya and also the detail calculation of space mean speed (including duration of time interval, sample vehicles, average time spent to travel the road length, segment length) that represent average speed in 15 minute interval. The detail tables of space mean speed calculation for the rest of the two segments is described in appendix B.

Table 9. Travel speed calculation of segment from Giorgis to Gebya in every 15 minute of analysis period

Duration on a video	Time (in second) that sample of vehicles spent to travel length(l) of segment										Avg. time (sec.)	Segment length (m)	Space mean speed
	1	2	3	4	5	6	7	8	9	10			
9:00 AM-9:15 AM	10	10	11	8	11	11	14	11	8	12	10.6	53.55	18.19
9:15 AM-9:30 AM	14	7	7	7	11	10	12	20	25	8	12.1	53.55	15.93
9:30 AM-9:45 AM	12	12	10	25	11	13	12	9	12	11	12.7	53.55	15.18
9:45 AM-10:00 AM	5	7	7	8	9	9	16	46	39	39	18.5	53.55	10.42
10:00 AM-10:15 AM	34	29	21	16	20	13	7	9	11	14	17.4	53.55	11.08
10:15 AM-10:30 AM	6	8	10	6	8	20	7	12	13	16	10.6	53.55	18.19
10:30 AM-10:45 AM	8	11	10	14	13	23	8	7	9	11	11.4	53.55	16.91
10:45 AM-11:00 AM	10	7	9	7	11	13	12	7	8	11	9.5	53.55	20.29
11:00 AM-11:15 AM	12	13	10	11	10	12	11	9	10	11	10.9	53.55	17.69
11:15 AM-11:30 AM	15	14	17	10	13	19	14	15	18	17	15.2	53.55	12.68
11:30 AM-11:45 AM	13	14	17	10	13	15	14	13	16	17	14.2	53.55	13.58
11:45 AM-12:00 AM	13	17	12	21	18	13	15	19	15	15	15.8	53.55	12.20

2.3.3.2. Volume

An observer fixed at a certain position along the roadway could measure the number of cars that passed in a given length of time. Volume is simply the number of vehicles that pass a given point on the roadway in a specified period of time. Volume is

commonly converted directly to flow (q), which is a more useful parameter in traffic analysis. Volume of all vehicle type for total three hours of analysis period is shown below.

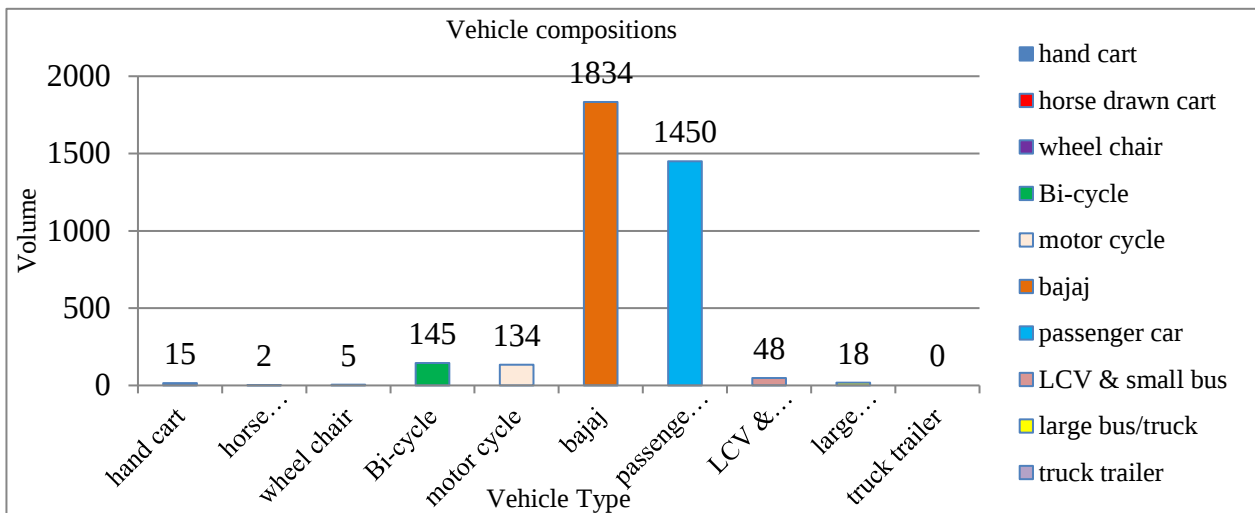


Figure 2. Vehicle compositions (Type of Vehicle Vs Volume) of Giorgis to Gebeya segment for 3 hours

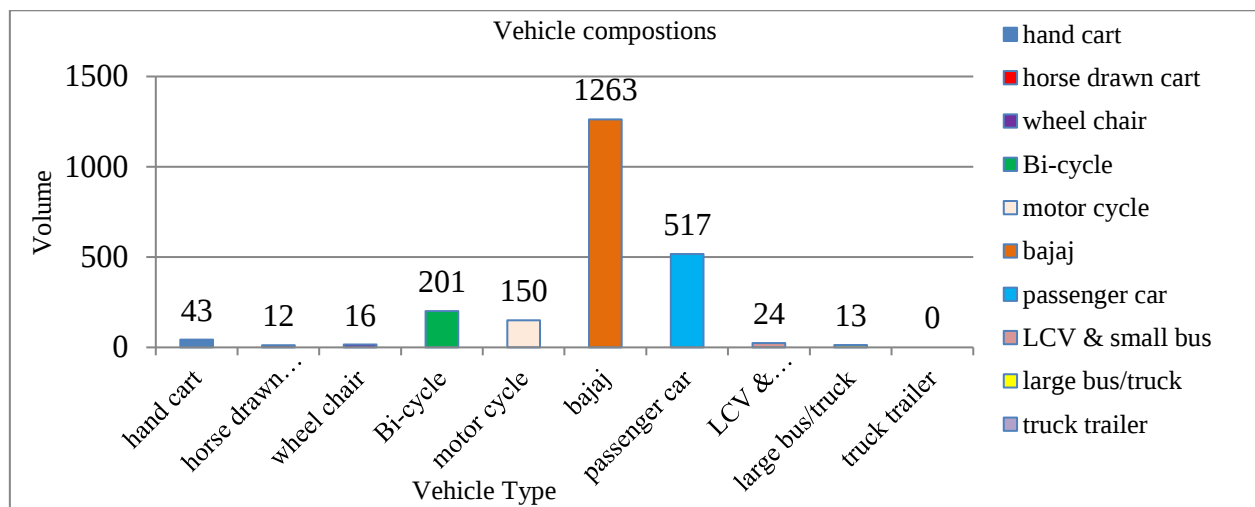


Figure 3. Vehicle compositions (Vehicle Vs Volume) of Zmamneshe building to Keble 4 Mesgid segment for 3 hours

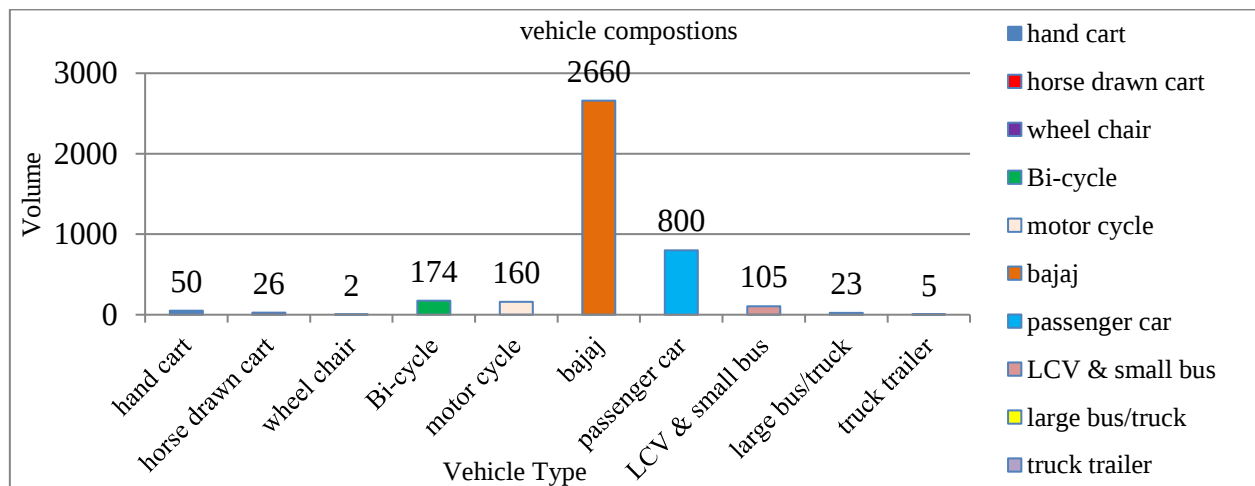


Figure 4. Vehicle compositions (Type of Vehicle Vs Volume) of Gebeya to Keble 14 NOC segment for 3 hours

2.3.3.3. Flow

Flow is traffic volume standardize to an hour, or vehicles per hour. Flow rate (q) defines as the equivalent hourly rate at which vehicles pass over a given point of a roadway during a given time interval in less than one hour usually 15-minutes.

Flow rate is given in terms of vehicles per hour [5].

Also on the video camera recorder count the numbers of vehicle that pass the given segment start line for about 15 minute and the unit is converted to vehicles per hour.

Table 10. Vehicle volume of segment from Giorgis to Gebya for every 15 minute of the analysis hour

Vehicle type in the road	Hand cart	Horse drawn cart	Wheel chair	Bi-cycle	Motor cycle	Bajaj	Passenger car	LCV/ small bus	large bus/ truck	Truck trailer
Passenger car unit	2	1.5	0.7	0.4	0.5	0.4	1	1.4	2.2	4
Duration of time	Number of vehicle by type									
9:00 AM-9:15 AM	0	1	1	8	10	159	137	6	2	0
9:15 AM-9:30 AM	1	0	0	8	9	154	126	8	1	0
9:30 AM-9:45 AM	1	0	0	14	5	155	122	7	2	0
9:45 AM-10:00 AM	0	0	0	9	9	136	108	7	3	0
10:00 AM-10:15 AM	1	0	2	13	14	170	126	9	3	0
10:15 AM-10:30 AM	1	0	0	10	17	165	118	1	0	0
10:30 AM-10:45 AM	1	0	1	19	10	171	102	4	2	0
10:45 AM-11:00 AM	3	0	0	14	13	161	117	3	1	0
11:00 AM-11:15 AM	4	0	0	10	6	139	130	2	1	0
11:15 AM-11:30 AM	2	0	0	7	12	135	105	1	1	0
11:30 AM-11:45 AM	0	1	1	16	15	160	124	0	1	0
11:45 AM-12:00 AM	1	0	0	17	14	129	135	0	1	0

Table 10 shows the flow of different vehicle types in every 15 minute interval period for 3 hours of a day, multiplying the passenger car unit by number of vehicles of different type and adding up in 15 minute interval will give number of vehicle in passenger car unit per 15 minute.

But for analysis purpose convert number of vehicles (of the unit passenger car unit per 15 minute) to a standard measurement called flow (expressed as number of vehicles per hour per lane) the table below shows the factors and typical flow value in Giorgis to Gebya road segment.

Table 11. Vehicle flow data of segment from Giorgis to Gebya for every 15 minutes of the analysis hour

Duration of time	No. of veh. (PCU/15 min.)	No. of veh. (PCU/ hour)	Road width (m)	Lane width (m)	No. of lane	No. of veh. (PCU/ hour/lane)
9:00 AM-9:15 AM	223.8	895.2	10.5	3.5	3	298.4
9:15 AM-9:30 AM	210.7	842.8	10.5	3.5	3	280.9
9:30 AM-9:45 AM	208.3	833.2	10.5	3.5	3	277.7
9:45 AM-10:00 AM	186.9	747.6	10.5	3.5	3	249.2
10:00 AM-10:15 AM	228.8	915.2	10.5	3.5	3	305.1
10:15 AM-10:30 AM	199.9	799.6	10.5	3.5	3	266.5
10:30 AM-10:45 AM	195.7	782.8	10.5	3.5	3	260.9
10:45 AM-11:00 AM	205.9	823.6	10.5	3.5	3	274.5
11:00 AM-11:15 AM	205.6	822.4	10.5	3.5	3	274.1
11:15 AM-11:30 AM	175.4	701.6	10.5	3.5	3	233.9
11:30 AM-11:45 AM	206.3	825.2	10.5	3.5	3	275.1
11:45 AM-12:00 AM	204.6	818.4	10.5	3.5	3	272.8

2.3.3.4. Density

Density is defined as the number of cars (at a fixed time) occupying a given length of a roadway. The unit used is vehicles per unit distance or vehicles per kilometer.

$\rho = \frac{n}{l}$, Where: - ρ = traffic density in vehicles per unit road length.

n = number of vehicles occupying some length of road way at time t and l = road length.

Since density is difficult to measure it is better to use the formula to get the number of vehicles in that specific road segment that means flow divided by speed that is counted for 15 minute of an hour later converted to the commonly known unit vehicle per kilometer. The table below shows the typical values of all the parameters of traffic flow modeling namely flow, speed and density of three selected segments [21].

Table 12. The values of parameters used for modeling on all selected road segments

Segments	Giorgis to Gebya			Zmammeshe building to Mesgid			Gebya to NOC		
Duration of time	Speed	Flow	Density	Speed	Flow	Density	Speed	Slow	Density
9:00 AM-9:15 AM	18.2	298.4	16.4	16.2	104.1	6.4	9.7	294.5	30.5
9:15 AM-9:30 AM	15.9	280.9	17.6	18.4	116.0	6.3	17.0	245.6	14.5
9:30 AM-9:45 AM	15.2	277.7	18.3	14.1	134.5	9.6	15.8	244.3	15.5
9:45 AM-10:00 AM	10.4	249.2	23.9	18.1	113.2	6.2	16.7	234.0	14.0
10:00 AM-10:15 AM	11.1	305.1	27.5	9.6	258.9	26.9	15.2	269.3	17.7
10:15 AM-10:30 AM	18.2	266.5	14.7	10.2	241.5	23.6	16.9	277.1	16.4
10:30 AM-10:45 AM	16.9	260.9	15.4	12.5	175.2	14.0	15.7	283.6	18.1
10:45 AM-11:00 AM	20.3	274.5	13.5	14.4	128.4	8.9	13.6	265.7	19.5
11:00 AM-11:15 AM	17.7	274.1	15.5	11.1	214.1	19.3	18.8	249.5	13.3
11:15 AM-11:30 AM	12.7	233.9	18.4	15.2	113.1	7.4	14.2	268.1	18.9
11:30 AM-11:45 AM	13.6	275.1	20.3	17.1	100.7	5.9	17.6	248.7	14.2
11:45 AM-12:00 AM	12.2	272.8	22.4	15.8	106.9	6.8	12.1	281.7	23.3

3. RESULTS AND DISCUSSION

In analysis of traffic flow modeling the proportion of vehicles play a great roll in affecting the traffic flow either by maximizing or decreasing performance

capacity of the road segments. The following figures show the percentage of vehicle seat in all selected segments.

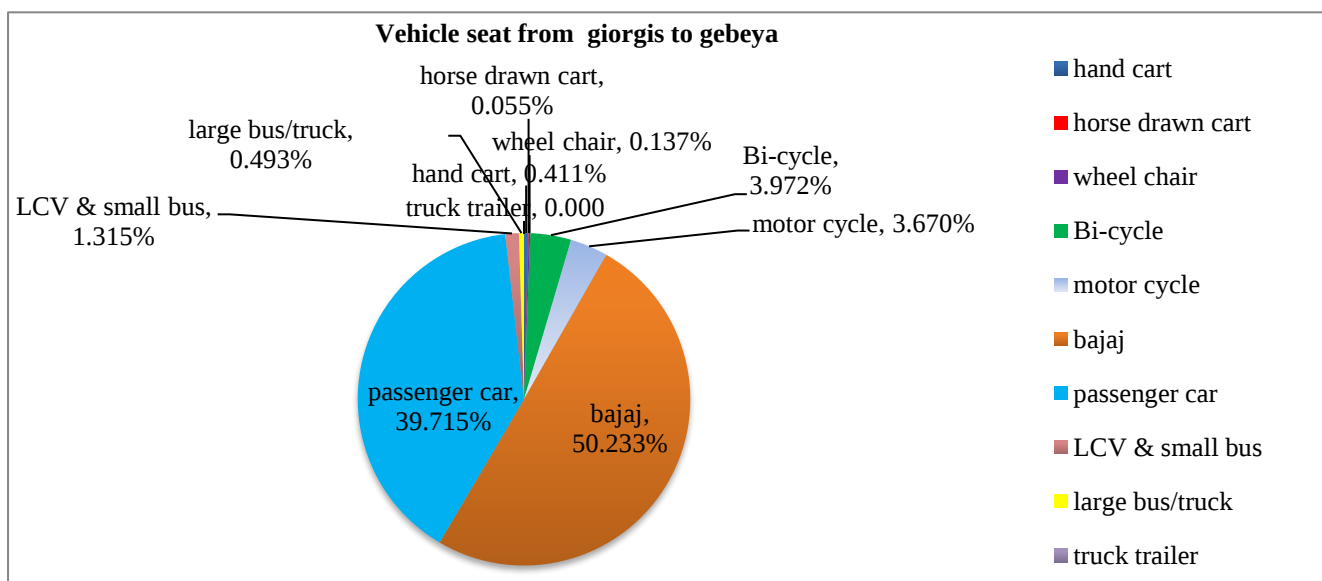


Figure 5. Vehicle seat on segment from Giorgis to Gebeya

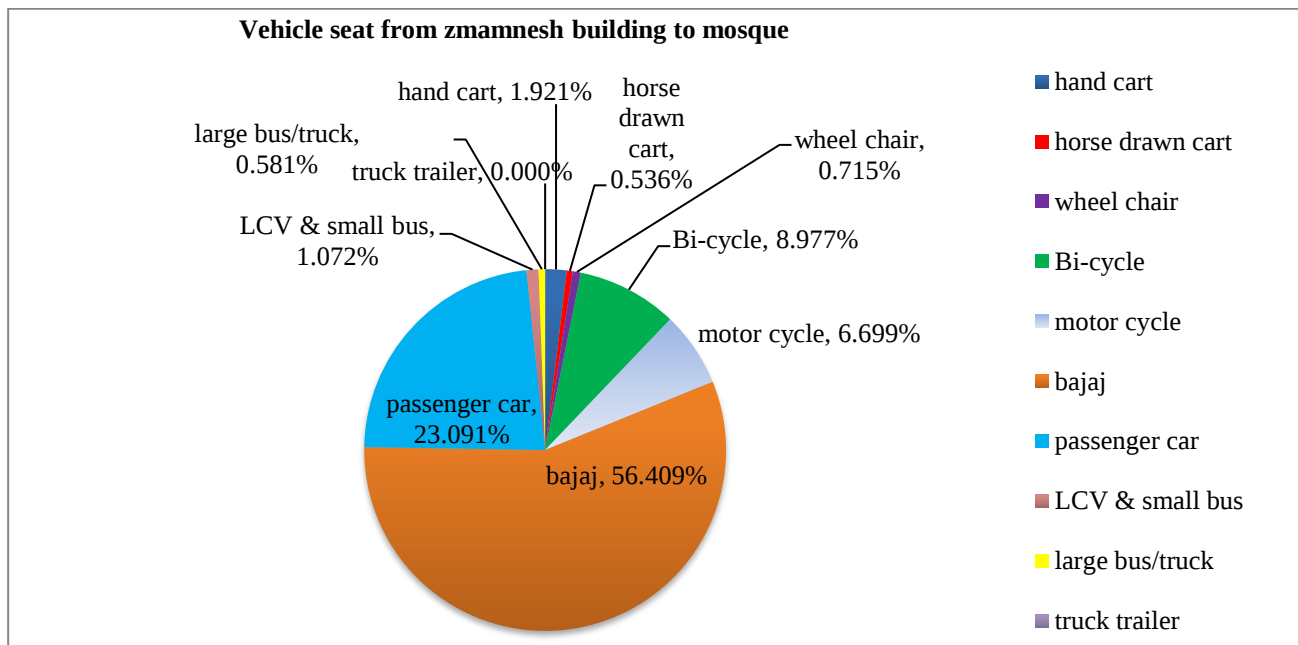


Figure 6. Vehicle seat on segment from Zmannesh building to Mesgid

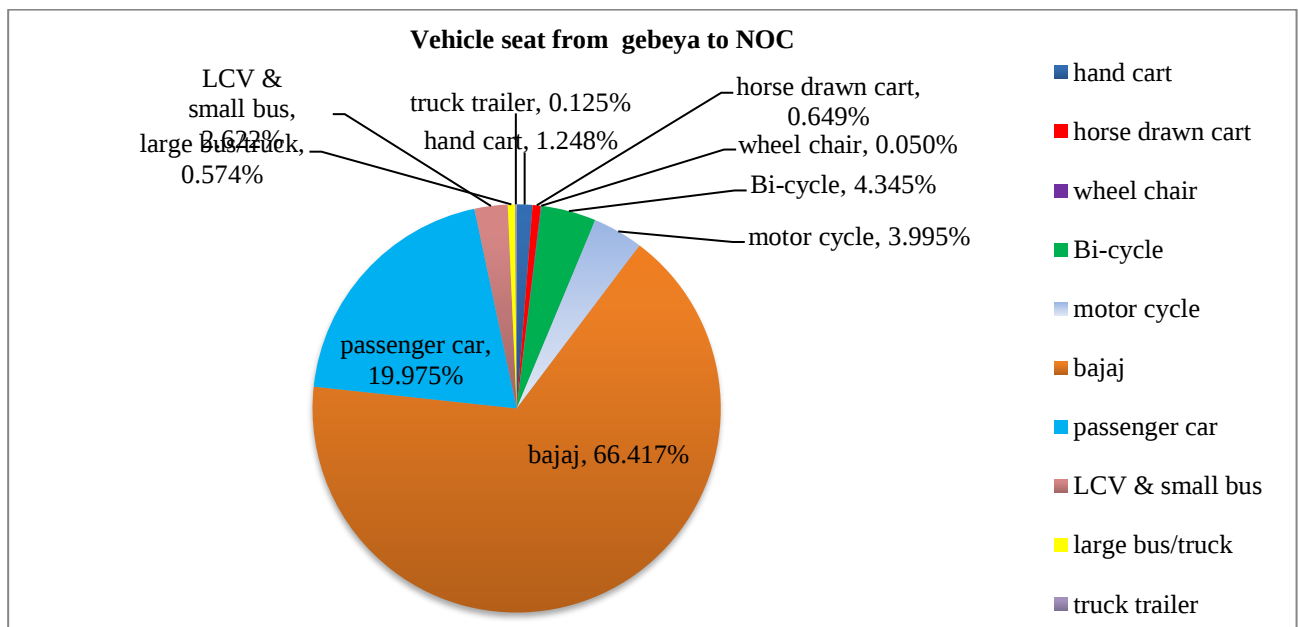


Figure 7. Vehicle seat on segment from Gebeya to NOC

3.1. Parameter value's and model analysis of segments

3.1.1. Analysis of segment from Giorgis to Gebya

Table 13. Summary of parametric values of segment from Giorgis to Gebya

Hours on the video	Speed (km/hr)	Flow (pc/hr/lane)	Density (pc/km/lane) = flow/speed
At no flow condition (no vehicles)	Maximum	Approach to 0	Approach to 0
At jam flow where vehicles stops	Approach to 0	Approach to 0	Maximum
9:00 AM-9:15 AM	18.19	298.4	16.41

9:15 AM-9:30 AM	15.93	280.93	17.63
9:30 AM-9:45 AM	15.18	277.73	18.3
9:45 AM-10:00 AM	10.42	249.2	23.92
10:00 AM-10:15 AM	11.08	305.07	27.53
10:15 AM-10:30 AM	18.19	266.53	14.66
10:30 AM-10:45 AM	16.91	260.93	15.43
10:45 AM-11:00 AM	20.29	274.53	13.53
11:00 AM-11:15 AM	17.69	274.13	15.5
11:15 AM-11:30 AM	12.68	233.87	18.44
11:30 AM-11:45 AM	13.58	275.07	20.26
11:45 AM-12:00 AM	12.2	272.8	22.36

3.1.1.1. The Greenshields Model as a prediction of relationship between the parameters

The linear relationship between speed and density model was first proposed by Greenshields in 1935 as a linear model to analyse the relationship between

speed, flow and density. The formulation is as follows: $u = u_f \left(1 - \frac{k}{k_j}\right)$.

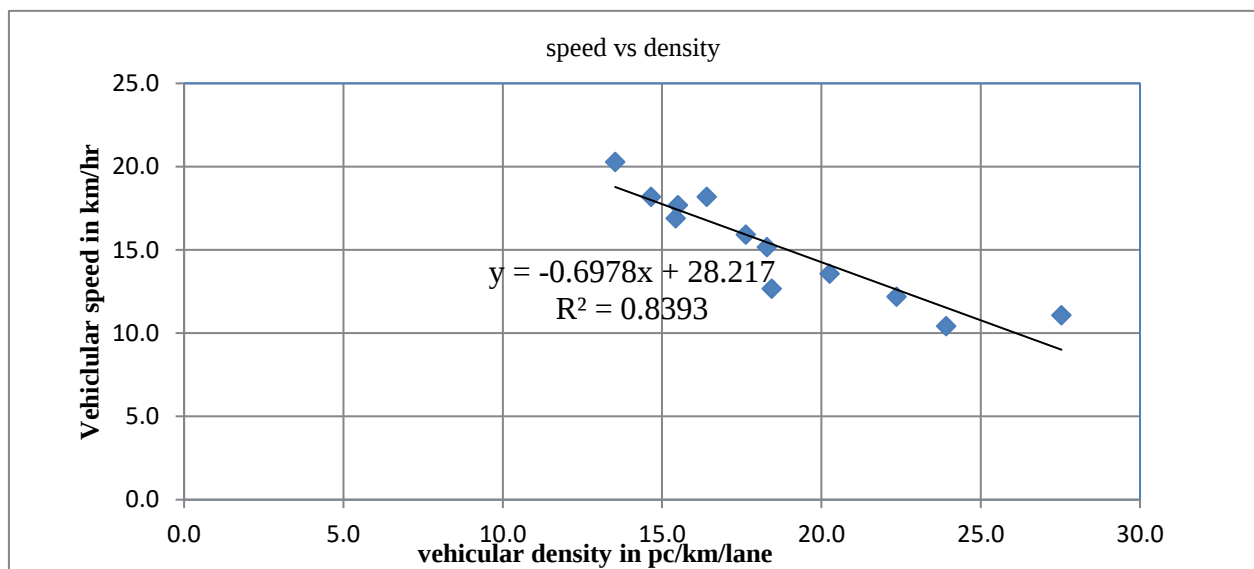


Figure 8. Greenshield's speed and density relationship on segment from Giorgis to Gebya

From the above chart which is performed using micro soft excel software the formula for the relationship between speed and density as $y = -0.6978x + 28.217$, x and y represent the vehicular density (k) and vehicular speed (u) respectively, this linear relationship can be written as the Greenshield's formulation of $u_f \frac{u_f}{k_j} * k$ therefor I

have the equilibrium of $u_f \frac{u_f}{k_j} * k = -0.6978k + 28.217$, which imply $u_f = 28.217$ and $-\frac{u_f}{k_j} * k = -0.6978k$ or $-\frac{u_f}{k_j} = -0.6978$ which means $k_j = \frac{-28.217}{-0.6978} = 40.48$.

The above Greenshield's model predict the relationship between two basic traffic flow

parameters namely speed and density of the selected road segment. Also free flow speed of vehicles and density of road have been calculated and the following results were obtained.

The free flow speed of vehicles is $u_f = 28.217$ km/hr at a very low flow rate,

Density of road when subjected to congested conditions is jam density $k_j = 40.48$ veh/km/lane

The basic relationship between these parameters is expressed as $u = u_f \left(1 - \frac{k}{k_j}\right)$ or using numerical constants as $u = 28.217 \left(1 - \frac{k}{40.48}\right)$.

3.1.1.2. The Greenberg Model as a prediction of relationship between parameters

The logarithmic relationship between speed and density was first proposed by Greenberg in 1959, the model uses a fluid flow analogy and data from the

Lincoln Tunnel in New York to establish a relationship as $u = u_c \ln \frac{k_j}{k}$.

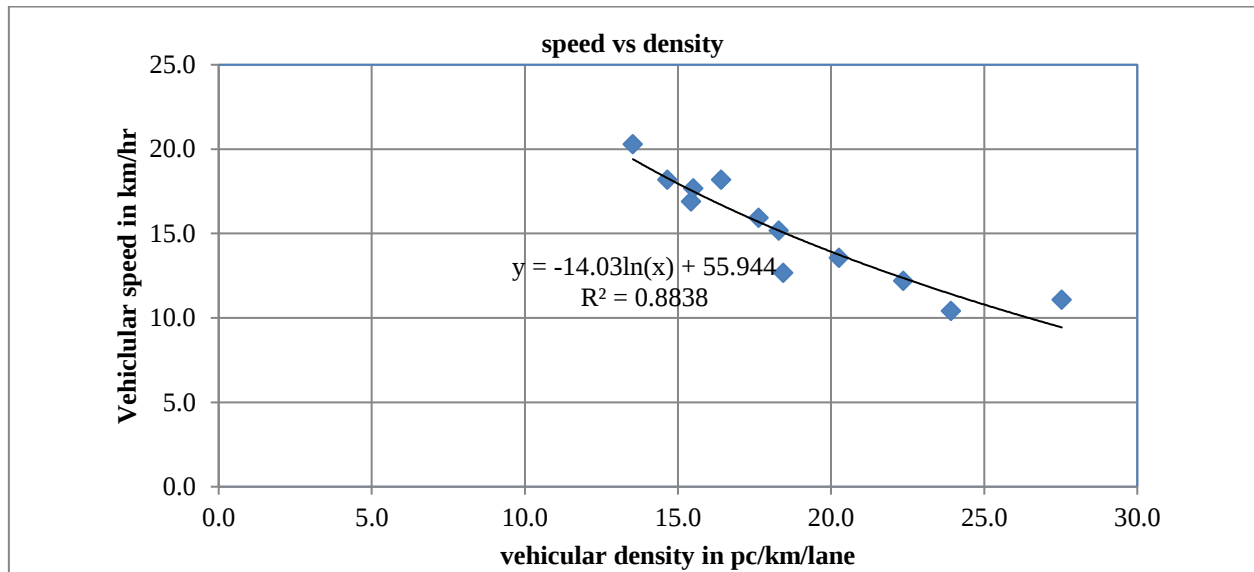


Figure 9. Greenberg's speed and density relationship on segment from Giorgis to Gebya

From the above chart which gives $y = -14.03\ln(x) + 55.944$ where $y = \text{speed } (v)$ and x is density (k) so that write as $v = -14.03\ln(k) + 55.944$ also Greenberg Model formulation is $u = u_c \ln \frac{k_j}{k}$ and since from logarithmic law one can write the formulation of Greenberg as $u = u_c \ln(k_j) - u_c \ln(k)$ than equalize as,

$$-14.03\ln(k) + 55.944 = u_c \ln(k_j) - u_c \ln(k)$$

since u_c and k_j had already known in the traffic modeling the constant term 55.944 in the regression model is equal to $u_c \ln(k_j)$ in the Greenberg's model and the unknown term $-14.03\ln(k)$ is equal to $-u_c \ln(k)$ that means, $-14.03\ln(k) = -u_c \ln(k)$, simplification gives $-14.03 = -u_c$ or speed at capacity is, $u_c = 14.03$ and $55.944 = u_c \ln(k_j)$ or $55.944 = 14.03 \ln(k_j)$ so that $\ln(k_j) = \frac{55.944}{14.03} = 3.9874$ also from logarithmic law $e^{\ln(k_j)} = e^{3.9874}$ gives $k_j = 53.914$.

The above Greenberg's model predict the relationship between two basic traffic flow parameters namely speed and density of the selected road segment, also average speed of vehicles at a capacity of the road and jam density of road where the speed of vehicles approaches to zero is calculated and the values are:-

The average speed of vehicles is $u_c = 14.03$ km/hr at optimum flow rate,

Density of road when subjected to maximum flow and minimum speed is jam density $k_j = 53.914$ veh/km/lane and

The basic relationship between these parameters is expressed as $u = u_c \ln \frac{k_j}{k}$ or using numerical constants as $u = 14.03 \ln \left(\frac{53.914}{k}\right)$.

3.2.1.3. The Underwood Model as a prediction of relationship between the parameters

Developed by Underwood in 1961, the model hypothesizes an exponential relationship between density and speed. The model is observed to generally have a better fit than the Greenshields and Greenberg models for the uncongested traffic

conditions but does not present a good fit to the data for congested conditions. The Underwood model is given as $u = u_f e^{\frac{-k}{k_c}}$ where:- k_c is the density at capacity.

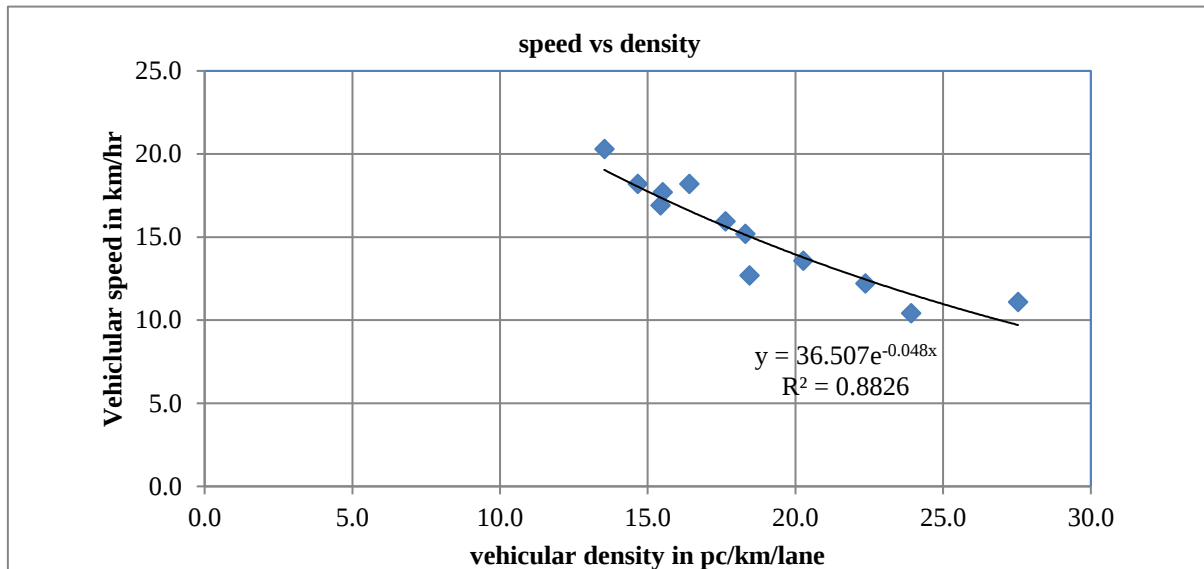


Figure 10. Underwood's speed and density relationship on segment from Giorgis to Gebya

From the above Underwood's model the relationship between the parameters having the x component as density (k) and y component as speed (v) and formulated as $y = 36.507e^{-0.048x}$ or $v = 36.507e^{-0.048k}$ and as the Underwood's proposed model $u = u_f e^{\frac{-k}{k_c}}$ implies the equalize formulas of $u_f e^{\frac{-k}{k_c}} = 36.507e^{-0.048k}$ gives as $u_f = 36.507$ and $\frac{-k}{k_c} = -0.048k$ therefore $k_c = \frac{1}{0.048} = 20.833$.

The above Underwood's model predict the relationship between two basic traffic flow parameters namely speed and density of the selected

road segment, also free flow speed of vehicles at a very low vehicles flow and density at capacity were the speed of vehicles approaches to optimum is calculated.

The free flow speed of vehicles is $u_f = 36.507$ km/hr at a very low flow rate,

Density of road when subjected to optimum density is $k_c = 20.833$ veh/km/lane and

The basic relationship between these parameters is expressed as $u = u_f e^{\frac{-k}{k_c}}$ or using numerical constants as $u = 36.507e^{\frac{-k}{20.833}}$.

3.2.2. Analysis of segment from Zmamneshe building to Mesgid

Table 14. Summary of parametric values of segment from Zmamneshe building to Mesgid

Hours on the video	Speed (km/hr)	Flow (pc/hr/lane)	Density (pc/km/lane) = flow/speed
At no flow condition (no vehicles)	Maximum	Approach to 0	Approach to 0
At jam flow where vehicles stops	Approach to 0	Approach to 0	Maximum
9:00 AM-9:15 AM	16.18	104.13	6.44
9:15 AM-9:30 AM	18.42	116.00	6.30
9:30 AM-9:45 AM	14.08	134.53	9.55
9:45 AM-10:00 AM	18.14	113.20	6.24
10:00 AM-10:15 AM	9.61	258.93	26.93
10:15 AM-10:30 AM	10.23	241.47	23.60

10:30 AM-10:45 AM	12.53	175.20	13.98
10:45 AM-11:00 AM	14.42	128.40	8.90
11:00 AM-11:15 AM	11.08	214.13	19.32
11:15 AM-11:30 AM	15.25	113.07	7.41
11:30 AM-11:45 AM	17.10	100.67	5.89
11:45 AM-12:00 AM	15.75	106.93	6.79

3.2.2.1. The Greenshields Model as a prediction of relationship between the parameters

The figure below shows the data of speed and corresponding density in the segment of the road from Zmammeshe building to Mesgid for every 15

minute of the analysis 3 hours period and also the best fit linear mathematics relation is drawn.

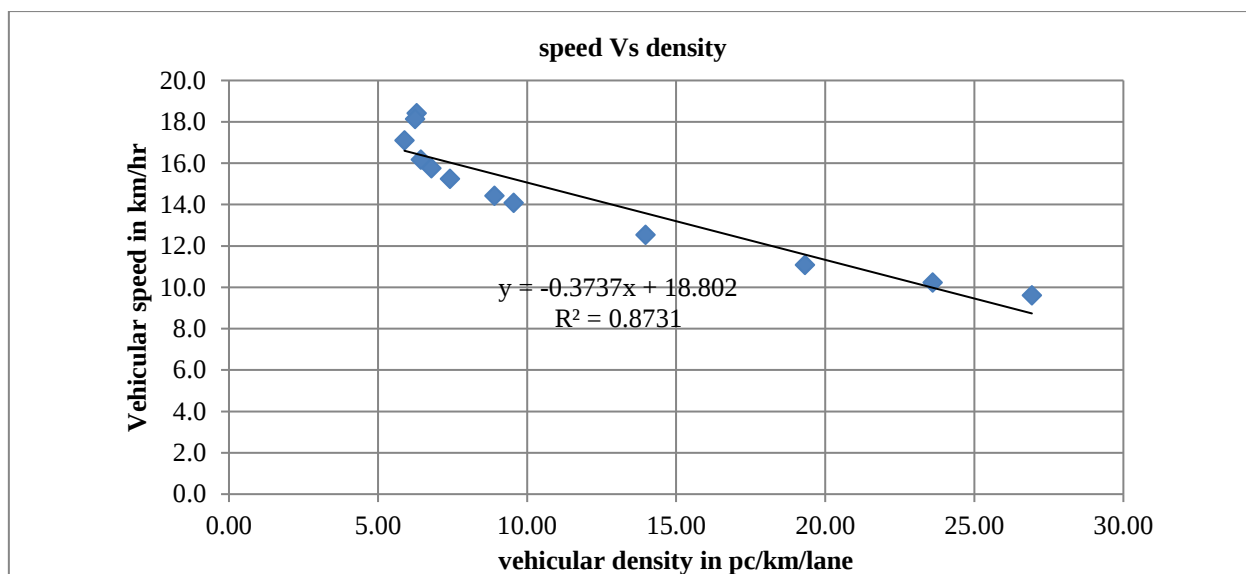


Figure 11. Greenshield's speed and density relationship on segment from Zmammeshe building to Mesgid

From the above chart which is performed using micro soft excel software the formula for the relationship between speed and density as $y = -0.3737k + 18.802$ or rewriting as Greenshield's model by $u_f \frac{u_f}{k_j} * k = -0.3737k + 18.802$ gives $u_f = 18.802$ and $k_j = 50.313$. The Greenshield's linear model predicts the values as follow.

The free flow speed of vehicles is $u_f = 18.802$ km/hr at a very low flow rate,

Density of road when subjected to congested condition is jam density $k_j = 50.313$ veh/km/lane,

The basic relationship between these parameters is expressed as $u = u_f \left(1 - \frac{k}{k_j}\right)$ or using numerical constants as $u = 18.802 \left(1 - \frac{k}{50.313}\right)$.

3.2.2.2. The Greenberg Model as a prediction of relationship between the parameters

The figure below shows the data of speed and corresponding density in the segment of the road from Zmammeshe building to Mesgid for every 15

minute of the analysis 3 hours period, also the best fit curve of logarithmic mathematics relation is drawn.

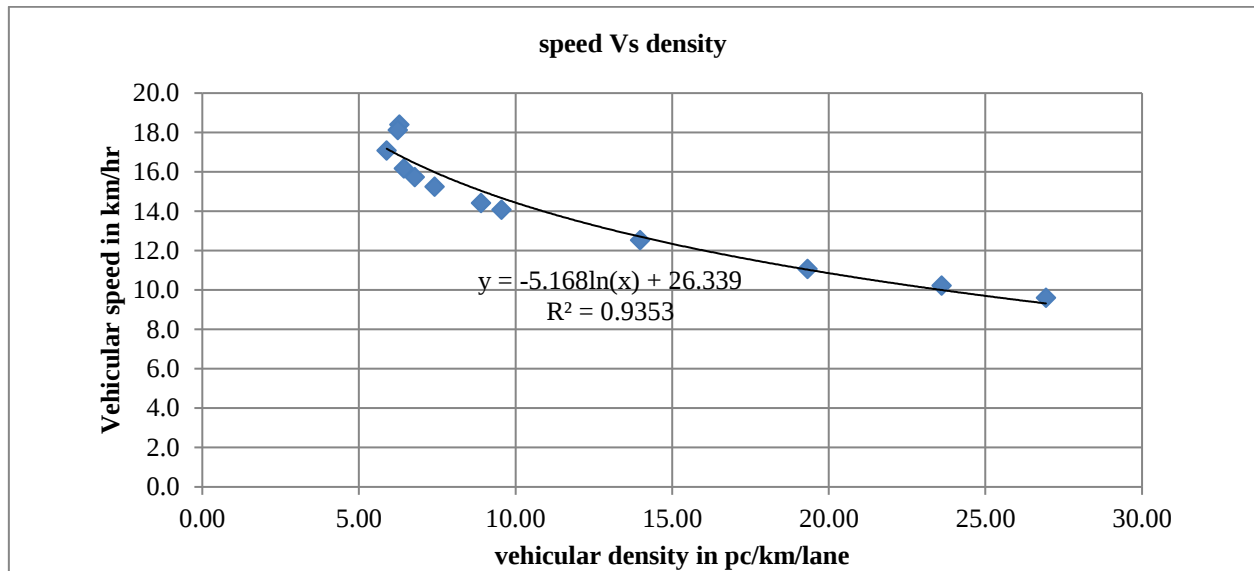


Figure 12. Greenberg's speed and density relationship on segment from Zmamneshe building to Mesgid

From the above chart which gives $y = -5.168\ln(x) + 26.339$ where y =speed (v) and x is density (k) so that let write as $v = -5.168 \ln(k) + 26.339$ which is equal to Greenberg Model formulation of $u = u_c \ln \frac{k_j}{k}$ so that could write as $-5.168\ln(k) + 26.339 = u_c \ln(k_j) - u_c \ln(k)$ therefore $u_c = 5.168$ and $k_j = 163.46$ and from this model summary of the following segment values is drawn.

The average travel speed of vehicles is $u_c = 5.168$ km/hr at optimum flow rate,

Density of road when subjected to maximum flow and minimum speed is jam density $k_j = 163.46$ veh/km/lane and

The basic relationship between these parameters is expressed as $u = u_c \ln \frac{k_j}{k}$ or using numerical constants as $u = 5.168 \ln \left(\frac{163.46}{k} \right)$.

3.2.2.3. The Underwood Model as a prediction of relationship between the parameters

The figure below shows the data of speed and corresponding density in the segment of the road from Zmamneshe building to Mesgid for every 15

minute of the analysis 3 hours period, also the best fit curve of exponential mathematics relation is drawn.

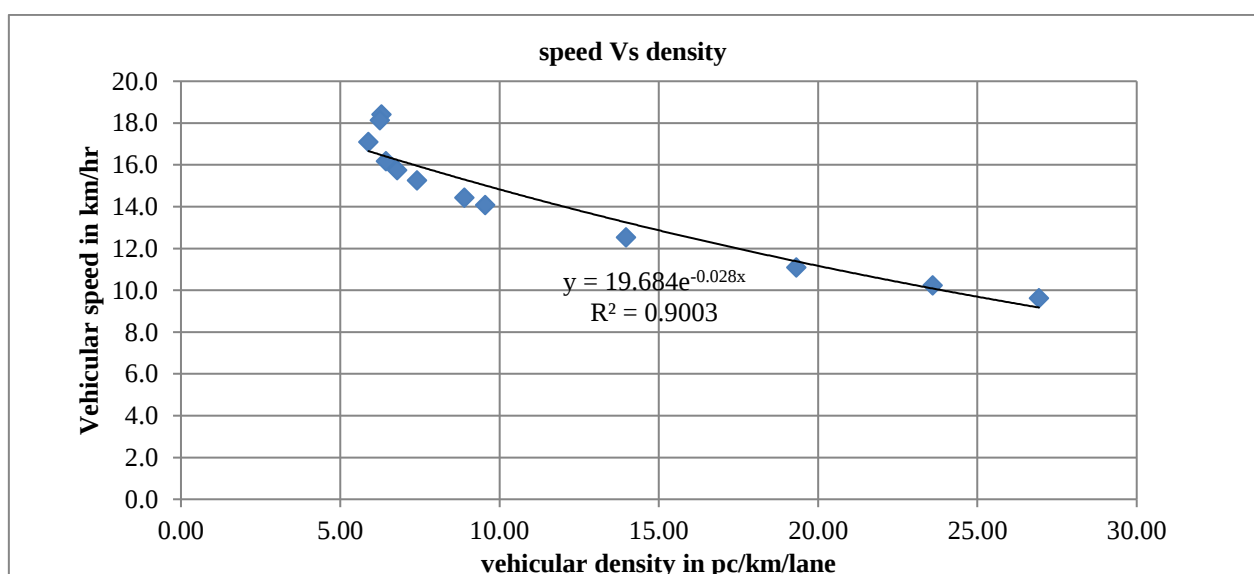


Figure 13. Underwood's speed and density relationship on segment from Zmamneshe building to Mesgid

The above figure gives the relation as $y = 19.684e^{-0.028x}$ or $v = 19.684e^{-0.028k}$ and as the

Underwood's proposed model $u = u_f e^{\frac{-k}{k_c}}$ implies equalize formulas $u_f e^{\frac{-k}{k_c}} = 19.684e^{-0.028k}$ which

gives $u_f=19.684$ and $\frac{-k}{k_c} = -0.028k$, $k_c = \frac{1}{0.028} = 35.71$
 and from the model the study draw the following
 parametric values of segment.
 the free flow speed of vehicles is $u_f = 19.684$ km/hr
 at a very low flow rate,

density of road when subjected to optimum density
 is $k_c = 35.71$ veh/km/lane and

The basic relationship between these parameters is
 expressed as $u = u_f e^{\frac{-k}{k_c}}$ or using numerical constants
 as $u = 19.684 e^{\left(\frac{-k}{35.71}\right)}$.

3.2.3. Analysis of segments from Gebya to NOC

Table 15. Summary of parametric values of segment from Gebya to NOC

Hours on the video	Speed (km/hr)	Flow (pc/hr/lane)	Density (pc/km/lane) = flow/speed
At no flow condition (no vehicles)	Maximum	Approach to 0	Approach to 0
At jam flow where vehicles stops	Approach to 0	Approach to 0	Maximum
9:00 AM-9:15 AM	9.67	294.53	30.46
9:15 AM-9:30 AM	16.97	245.6	14.47
9:30 AM-9:45 AM	15.79	244.27	15.47
9:45 AM-10:00 AM	16.74	234	13.98
10:00 AM-10:15 AM	15.21	269.33	17.71
10:15 AM-10:30 AM	16.86	277.07	16.44
10:30 AM-10:45 AM	15.69	283.6	18.07
10:45 AM-11:00 AM	13.63	265.73	19.49
11:00 AM-11:15 AM	18.76	249.47	13.3
11:15 AM-11:30 AM	14.18	268.13	18.92
11:30 AM-11:45 AM	17.57	248.67	14.15
11:45 AM-12:00 AM	12.11	281.73	23.26

3.2.3.1. The Greenshields Model as a prediction of relationship between the parameters

The Greenshields linear relation between speed and
 density for a segment from Gebya to NOC is shown

below in [figure 14](#) using the value of parameters
 tabulated above.

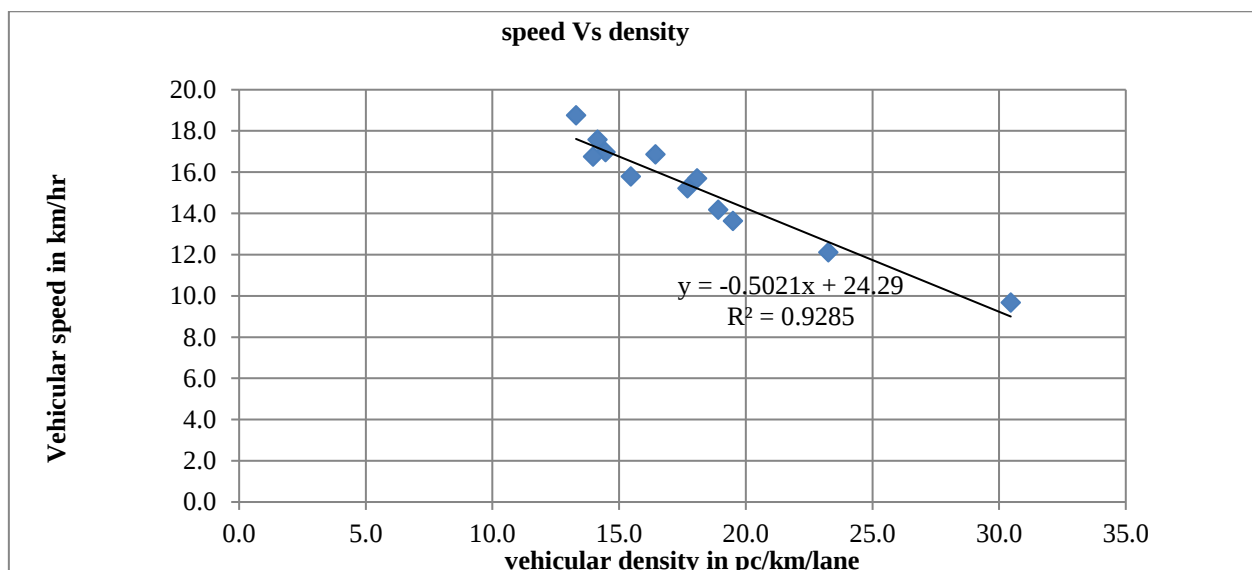


Figure 14. Greenshield's speed and density relationship on segment from Gebya to NOC

From the above chart which is performed using micro soft excel software the formula for the relationship between speed and density as $y = -0.5021k + 24.29 = u_f - \frac{u_f}{k_j} * k$ therefor the equilibrium express as $u_f = 24.29$ and $-\frac{u_f}{k_j} * k = -0.5021k$ or $-\frac{u_f}{k_j} = -0.5021$ that means $k_j = \frac{-24.29}{-0.5021} = 48.377$. The above Greenshield's model predicts the relationship between two basic traffic flow parameters namely

speed and density of the selected road segment and the following value are recorded.

The free flow speed of vehicles is $u_f = 24.29$ km/hr at a very low flow rate,

Density when subjected to congested condition is jam density $k_j = 48.377$ veh/km/lane and

The basic relationship between these parameters is expressed as $u = u_f \left(1 - \frac{k}{k_j}\right)$ or using numerical constants as $u = 24.29 \left(1 - \frac{k}{48.377}\right)$.

3.2.3.2. The Greenberg Model as a prediction of relationship between parameters

Greenberg's logarithmic model of speed density relation is described as a form of figure and a formula.

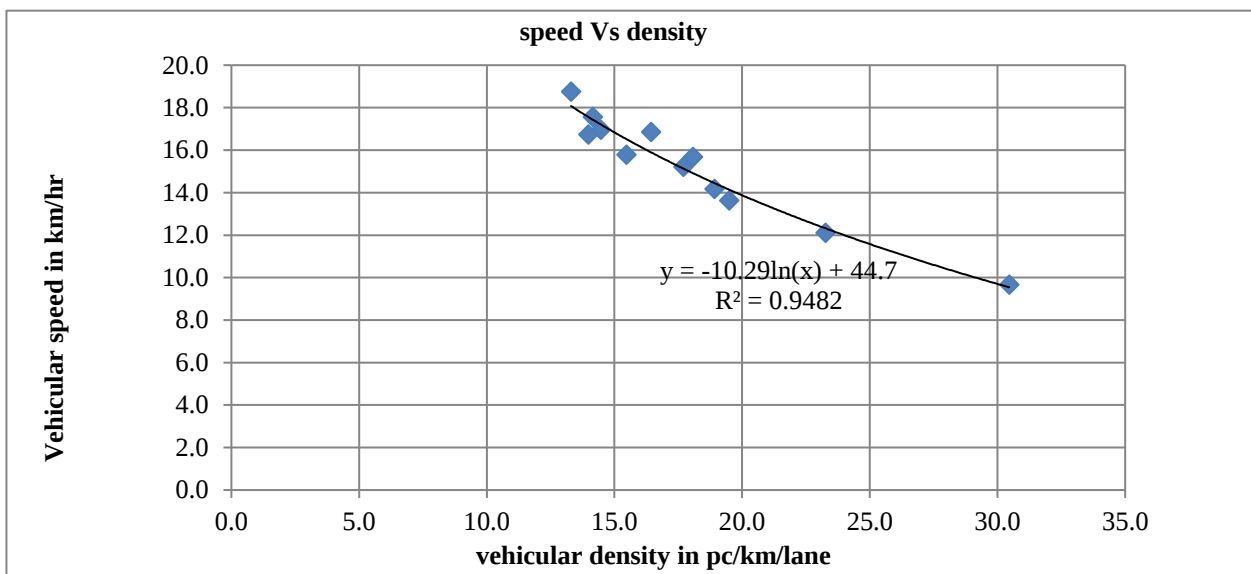


Figure 15. Greenberg's speed and density relationship on segment from Gebya to NOC

From the above chart we have $y = -10.29\ln(k) + 44.7$ and also as a Greenberg Model formulation of $u = u_c \ln \frac{k_j}{k}$, and since from logarithmic law one can write the formulation of Greenberg as $u = u_c \ln(k_j) - u_c \ln(k)$ than equalize as, $-10.29\ln(k) + 44.7 = u_c \ln(k_j) - u_c \ln(k)$ calculation would give the values of $u_c = 10.29$ and $k_j = 77.016$. The Greenberg's model predicts the relationship between two basic traffic flow parameters namely speed and density of

the selected road segment and the following value were obtained.

The average speed of vehicles is $u_c = 10.29$ km/hr at optimum flow rate,

Density of road when subjected to maximum flow and minimum speed is jam density $k_j = 77.016$ veh/km/lane and

The basic relationship between these parameters is expressed as $u = u_c \ln \frac{k_j}{k}$ or using numerical constants as $u = 10.29 \ln \left(\frac{77.016}{k}\right)$.

3.2.3.3. The Underwood Model as a prediction of relationship between the parameters

Underwood predicts the relationship between speed and density as exponential relation, and the figure

below shows the value of this two parameters and the best fit curve.

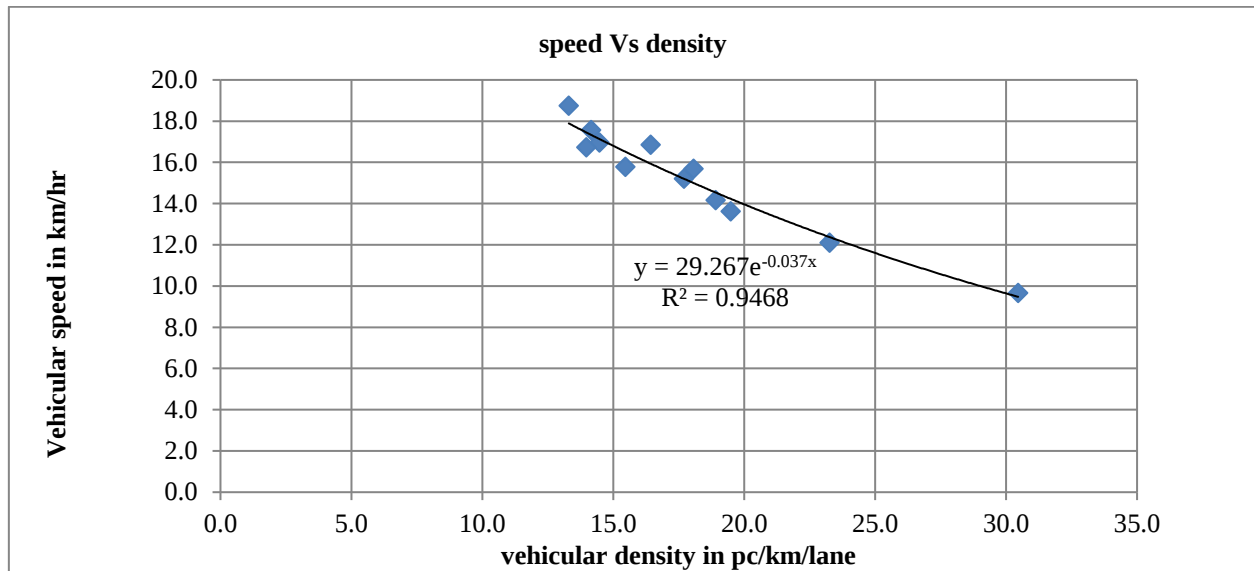


Figure 16. Underwood's speed and density relationship on segment from Gebya to NOC

From the above Underwood's model which gives as follows $y = 29.267e^{-0.037x}$ or $v = 29.267e^{-0.037k}$ and the Underwood's proposed model of $u = u_f e^{\frac{-k}{k_c}}$ implies equilibrium formulae as $u_f e^{\frac{-k}{k_c}} = 29.267e^{-0.037k}$ which gives as $u_f = 29.267$ and $\frac{-k}{k_c} = -0.037k$, $k_c = \frac{1}{-0.037} = 27.03$. The Underwood's model predicts the relationship between two basic traffic flow parameters and values are recorded as;

Free flow speed of vehicles is $u_f = 29.267$ km/hr at a very low flow rate,

Density of road when subjected to optimum density is $k_c = 27.03$ veh/km/lane and

The basic relationship between these parameters is expressed as $u = u_f e^{\frac{-k}{k_c}}$ or using numerical constants as $u = 29.267 e^{\left(\frac{-k}{27.03}\right)}$.

Table 16. Summary of formulas of speed and density relationship, typical value and goodness fit (using Greenberg, Greenshield, Underwood models for all selected segments)

Segments		From Giorgis to Gebya	From Zmammeshe building to Mesgid	From Gebya to NOC
Greenshield Model	Equation	$u = 28.217 \left(1 - \frac{k}{40.48}\right)$	$u = 18.802 \left(1 - \frac{k}{50.313}\right)$	$u = 24.29 \left(1 - \frac{k}{48.377}\right)$
	Computed values	$u_f = 28.217$ $k_j = 40.48$	$u_f = 18.802$ $k_j = 50.313$	$u_f = 24.29$ $k_j = 48.377$
	R ² and r	R ² = 0.8393 and r = ±0.916	R ² = 0.8731 and r = ±0.934	R ² = 0.9285 and r = ±0.9636
Greenberg Model	Equation	$u = 14.03 \ln\left(\frac{53.914}{k}\right)$	$u = 5.168 \ln\left(\frac{163.46}{k}\right)$	$u = 10.29 \ln\left(\frac{77.016}{k}\right)$
	Computed values	$u_c = 14.03$ $k_j = 53.914$	$u_c = 5.168$ $k_j = 163.46$	$u_c = 10.29$ $k_j = 77.016$
	R ² and r	R ² = 0.8838 and r = ±0.940	R ² = 0.9353 and r = ±0.967	R ² = 0.9482 and r = ±0.974
Underwood Model	Equation	$u = 36.507 e^{\left(\frac{-k}{20.833}\right)}$	$u = 19.684 e^{\left(\frac{-k}{35.71}\right)}$	$u = 29.267 e^{\left(\frac{-k}{27.03}\right)}$
	Computed values	$u_f = 36.507$ $k_c = 20.833$	$u_f = 19.684$ $k_c = 35.71$	$u_f = 29.267$ $k_c = 27.03$
	R ² and r	R ² = 0.8604 and r = ±0.927	R ² = 0.9263 and r = ±0.962	R ² = 0.9603 and r = ±0.979

Table 17. Significance of correlation for comparison

$r (\pm)$	Significance of correlation
0-0.2	No correlation
0.2-0.4	Very poor
0.4-0.6	Poor
0.6-0.8	Good
0.8-1	Very good

In hierarchy of significance level of the correlation between speed and density the above table gives

more detail on correlation of speed and density.

3.2.4. Analysis of all three segments as a whole representing Bahir Dar city

Since the separate segment does not represent the model relationship between speed and density as a town, the study combine the flow parameters of three

segments than after the model relationship will draw that represent Bahir Dar city as a town.

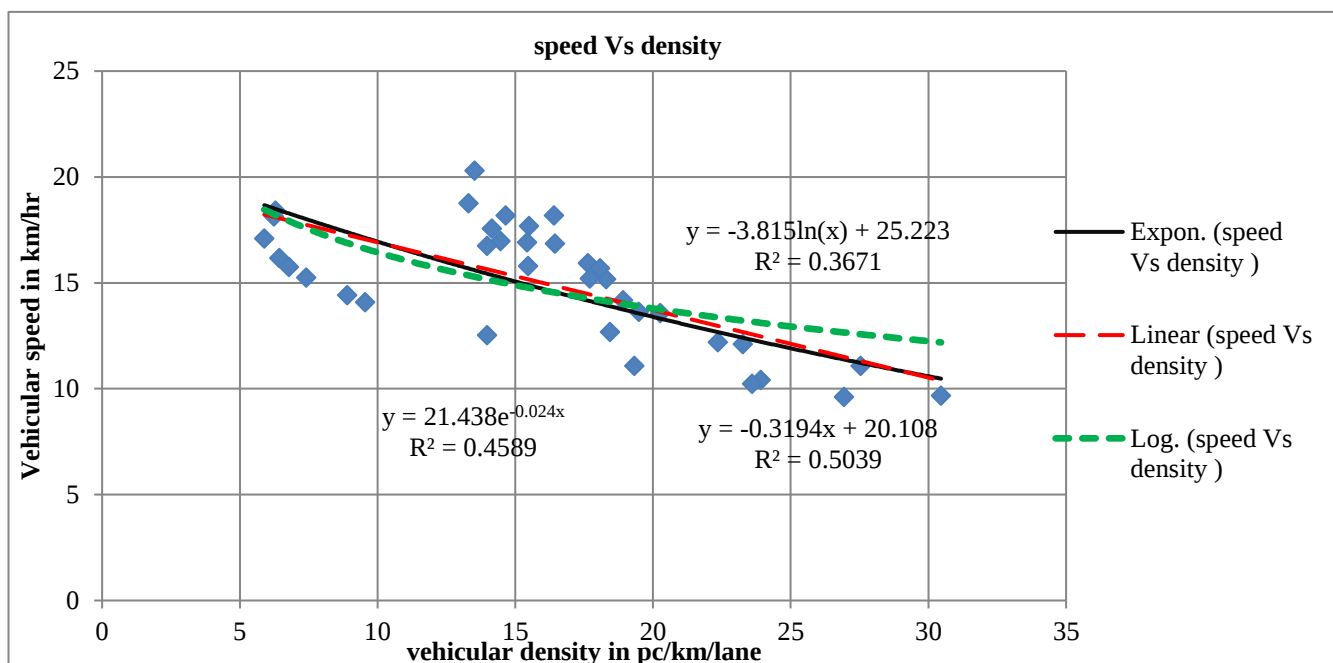


Figure 17. Summarized Plot of Speed vs. Density represents congested Segments in Bahir Dar city (Greenshield, Greenberg and Underwood model)

From the above chart based on best fit relationship between speed and density of three selected road segments that most possibly representative Bahir Dar city traffic flow condition as a whole is underwood's

exponential relationship model, because the goodness fitness value (R^2) is greater than others linear and logarithmic relation ($R^2 = 0.5385 > 0.5039 > 0.3671$).

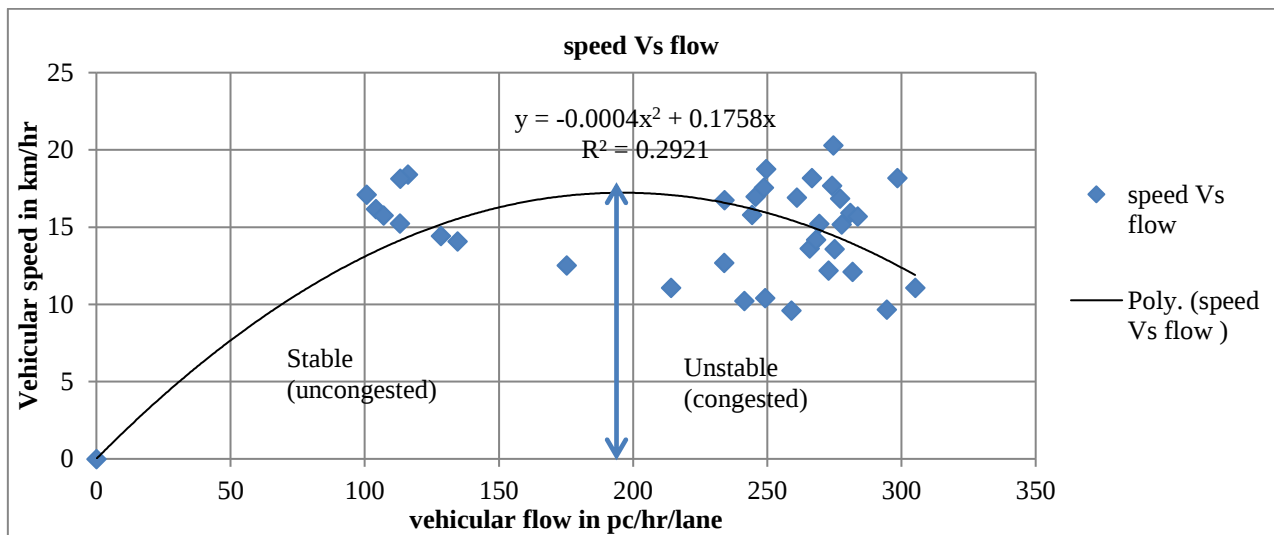


Figure 18. Summarized Plot of Speed vs. flow represents congested Segments in Bahir Dar city

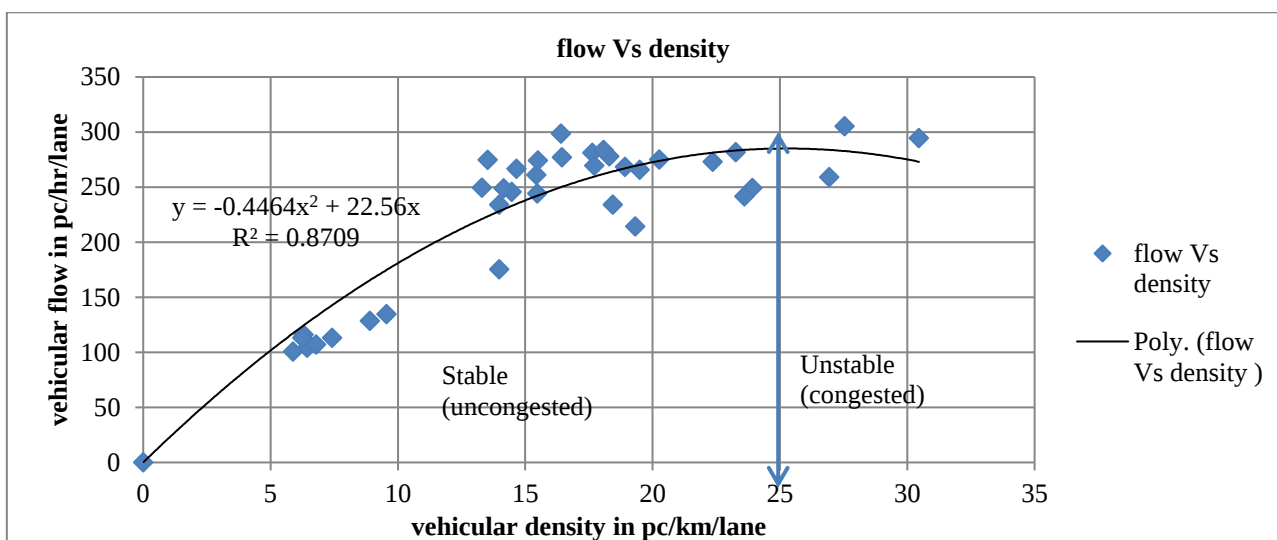


Figure 19. Summarized Plot of flow vs. density represents congested Segments in Bahir Dar city

The above two [figure 18](#) and [figure 19](#) shows the relationship between speed-flow and flow-density of combined data on three of all selected segments respectively. From the figure more of the vehicular data lies under congested vehicle flow state and uncongested vehicle density state, also the combined segments flow parameter typical value of Bahir Dar city road segment shown in the above figures recorded as the optimum flow rate of 220 pc/hr/lane occurs when speed is 19.3 km/hr and the optimum flow rate of 285 pc/hr/lane occurs when the density of road segment is about 25 pc/km/lane.

3.3. Level of service analysis of urban street

Level of service (LOS) is a quality measure describing operational conditions within a traffic stream, generally in terms of such service measures as speed and travel time, freedom to maneuver, traffic interruptions, and comfort and convenience.

Since from the above summarized plot of Bahir Dar city multi-lane high way segments the relationship between flow and density having $R^2 = 0.8657$ ($r=0.93$) is more representative and significance than relationship between flow and speed having $R^2 = 0.2542$ ($r=0.50$) therefore as the summary, the city seems operating with optimum flow rate of 285 pc/hr/lane at vehicular road density of 25 pc/km/lane and calculated speed from flow-density curve is about 11.5 km/hr.

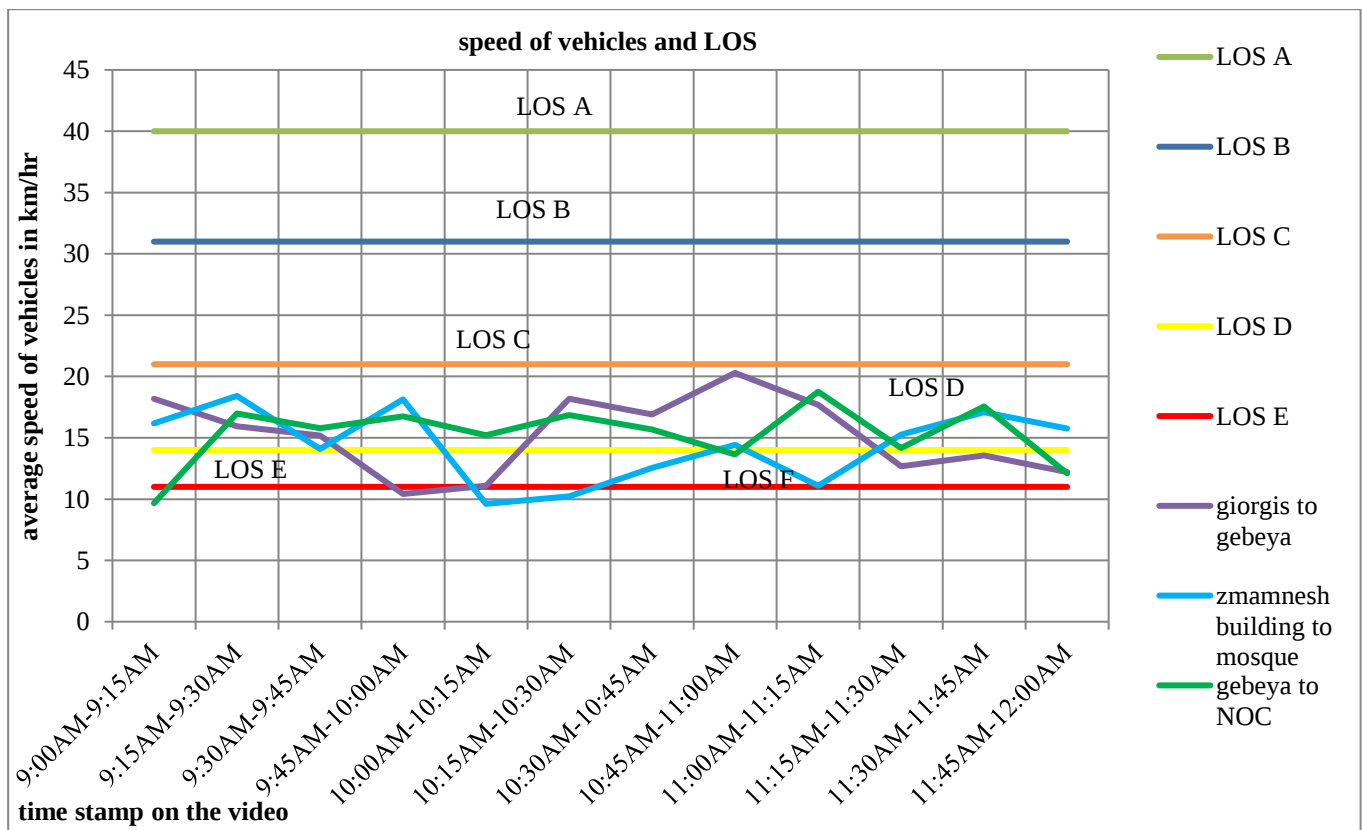
Urban Street LOS is based on average through vehicle travel speed for the segment or for the entire street under consideration. Travel speed is the basic service measure for urban streets. The average travel speed is computed from the running times on the urban Street [\[5\]](#).

Table 18. Urban street LOS by class (according to high way capacity manual, 2000)

Urban Street Class	I	II	III	IV
Range of free flow speeds (FFS)	55 to 45 mi/h	45 to 35 mi/h	35 to 30 mi/h	35 to 25 mi/h
Typical FFS	50 mi/h	40 mi/h	35 mi/h	30 mi/h
LOS	Average Travel Speed (mi/h)			
A	>42	>35	>30	>25
B	>34-42	>28-35	>24-30	>19-25
C	>27-34	>22-28	>18-24	>13-19
D	>21-27	>17-22	>14-18	>9-13
E	>16-21	>13-17	>10-14	>7-9
F	≤16	≤13	≤10	≤7

In [Table 18](#) the level of service of urban road segments is shown by average travel speed and urban street segment classes in which urban classes is identified using free flow speed of vehicles under low vehicular flow rate. But in the field study it is hard to measure the free flow speed of vehicles so using the alternative mentioned by high way capacity

manual is the right choose, which is design speed of the street that means according to Ethiopian Road Authority manual design speed of DC8 urban street is 50 km/hr or 31.25 mi/hr that shows the urban road class of IV. The figure below shows the level of service of all three selected segments using vehicular average travel speed and Urban Street Class IV.

**Figure 20.** Level of service of all road segments based on speed

3.4. Capacity analysis of urban road

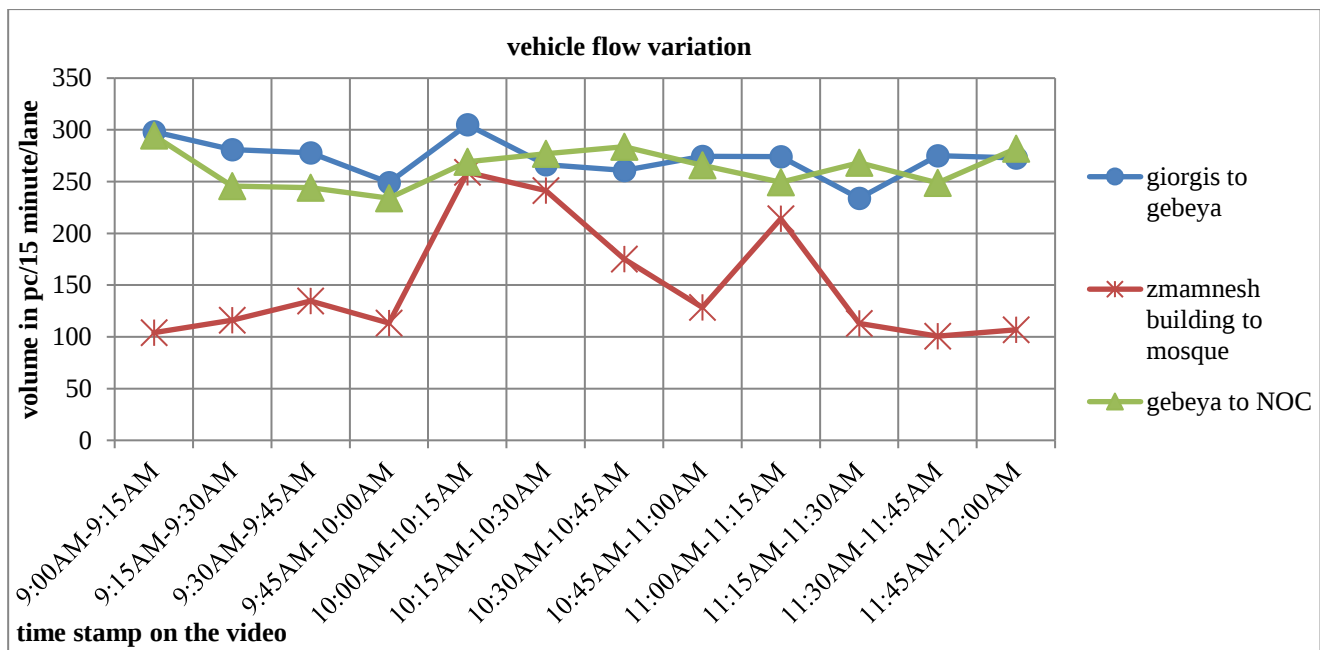


Figure 21. Flow variation of all segments in every 15 minute of analysis period

The figure above shows the level of service analysis using average travel speed of segments in every 15 minutes of the analysis period as one can see the majority of hours is operating under LOS D for all selected segments so since the congested condition of Bahir Dar city is represented by this three segments the study conclude level of service of the city in congested hour and road segment is LOS D.

The capacity of total six lane divided two way Sub arterial road according to Indian road congress manual design capacity is 4300 pc/h and directional three lane capacity is 2150 pc/h. The volume on average in three hours of segment from Giorgis to Gebeya is 817 pc/h, from Zmamnesh building to Mesgid is 452 pc/h and segment from Gebeya to NOC is 790 pc/h which is much lesser than design service volume.

Table 19. Volume to capacity ratio of all segments

Segments	Capacity directional three lane (IRC in pc/h)	Service volume (pc/h)	Volume to capacity ratio (v/c)
From Giorgis to Gebeya	2150	817	0.38
From Zmamneshe building to Mesgid	2150	452	0.21
From Gebeya to NOC	2150	790	0.367

4. CONCLUSION

In this study of traffic flow modeling in Bahir Dar city of selected road segments was conducted aimed firstly to give information about road way and traffic characteristics like traffic composition, vehicles seat on segments, traffic flow parameter (speed, flow, density and relationship of segments and also combined effect of three segments representing

Bahir Dar city as a whole was performed) and secondly the study indicate segments performance measure by using analysis of level of service and capacity. In traffic characteristics of different segment in all three hours of analysis period the following data where recorded, segment from Giorgis to Gebeya;

About 1834 vehicles are bajaj from 3561 vehicles having about 50.23 % of all traffic share,
Speed as high as 10.4 km/hr and as low as 20.3 km/hr was recorded,

Flow as high as 233.9 pc/hr/lane and as low as 305.1 pc/hr/lane was recorded,

Density as high as 13.5 pc/km/lane and as low as 27.5 pc/km/lane was recorded as far the best fit curve of speed vs. density relationship for specified segment is expressed by using $u=14.03 \ln(\frac{53.914}{k})$ of Greenberg's Model.

The segment from Zmamnesh building to Keble 4 Mesgid the following characteristics recorded;

About 1263 vehicles are bajaj from 2239 vehicles having about 56.41 % of all traffic share,

Speed as high as 9.6 km/hr and as low as 18.4 km/hr was recorded,

Flow as high as 100.7 pc/hr/lane and as low as 258.9 pc/hr/lane was recorded,

Density as high as 5.9 pc/km/lane and as low as 26.9 pc/km/lane was recorded as far the best fit curve of speed vs. density relationship for specified segment is expressed by using $u=5.168 \ln(\frac{163.46}{k})$ of Greenberg's Model.

The segment represents from Gebya to NOC and the following attributes were recorded;

About 2660 vehicles are bajaj from 4005 vehicles having about 66.42 % of all traffic share,

Speed as high as 9.7 km/hr and as low as 18.8 km/hr was found,

Flow as high as 234.0 pc/hr/lane and as low as 294.5 pc/hr/lane was found,

Recommendations:

Travel speed of vehicles is below the design posted speed limit that causes delay and anxiety for road users. There have to be a measure that render in reducing and minimizing interruption of vehicular traffic flows, the following measure must provide to enhance the capacity and LOS.

Proper and fixed crossing for a pedestrian to use, appropriate road marking, public education.

Give awareness for pedestrian to use proper cross roads and avoid jay walking to cross.

Density as high as 13.3 pc/km/lane and as low as 30.5 pc/km/lane was found as far the best fit curve of speed vs. density relationship for specified segment is expressed by using Underwood's Model of $u= 29.267 e^{\frac{-k}{27.03}}$.

Traffic share of segment from Gebya to NOC where subjected to higher traffic share both by all sum of traffic vehicles and Bajaj taxi vehicles also the vehicles flow of segment from Zmamnesh building to Mesgid is much more less than the flow of other two segments.

Considering all three segments of the city that essentially represent the traffic characteristics of congested segment of Bahir Dar city, the following attribute was recorded;

City level modeling having a best fit for speed vs. density relation is expressed by Underwood's Model as $u = 21.438e-0.024k$ having $R^2 = 0.5385$, $r = \pm 0.734$ which shows there is a good relationship between speed and density.

Performance measure of three segments were conducted and according to the analysis the level of service of all selected segments above 60% of the analysis hours is operating under LOS D and capacity on average in three hour of segment from Giorgis to Gebeya is 817 pc/h, from Zmamnesh building to mosque is 452 pc/h and segment from Gebya to NOC is 790 pc/h and the volume to capacity ratio of all selected segment is below saturation level.

Avoiding on the street parking so that all three lanes is function able for traffic movement.

Install the overpass facility for pedestrian.

Impose restriction on slow moving heavy vehicle and animal drawn cart.

Minimizing the number of Bajaj and replace by taxi, also the passenger car unit of Bajaj must be restudied as it is highly affected the analysis.

The study highlights that adjusting traffic signals during peak hours could reduce congestion by 20%, making it a practical solution for Bahir Dar.

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AUTHORS CONTRIBUTION

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CONFLICT OF INTEREST

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5. REFERENCES

- [1] Herman R, Montroll EW, Potts RB, Rothery RW. Traffic dynamics: analysis of stability in car following. Operations research. 1959 Feb;7(1):86-106. [\[View at Google Scholar\]](#); [\[View at Publisher\]](#).
- [2] Lighthill MJ, Whitham GB. On kinematic waves II. A theory of traffic flow on long crowded roads. Proceedings of the royal society of london. series a. mathematical and physical sciences. 1955 May 10;229(1178):317-45. [\[View at Google Scholar\]](#); [\[View at Publisher\]](#).
- [3] Prigogine I, Herman R. Kinetic theory of vehicular traffic. 1971. No. 100 pp. [\[View at Google Scholar\]](#); [\[View at Publisher\]](#).
- [4] Hoogendoorn SP, Bovy PH. State-of-the-art of vehicular traffic flow modelling. Proceedings of the Institution of Mechanical Engineers, Part I: Journal of Systems and Control Engineering. 2001 Jun 1;215(4):283-303. [\[View at Google Scholar\]](#); [\[View at Publisher\]](#).
- [5] Manual HC. Highway capacity manual. Washington, DC. 2000;2(1):1. [\[View at Google Scholar\]](#); [\[View at Publisher\]](#).
- [6] Lomax T, Turner S, Eisele B, Schrank D, Geng L, Shollar B. Refining the real-time urban mobility report. Texas Transportation Institute. University Transportation Center for Mobility; 2012 Mar 1. [\[View at Google Scholar\]](#); [\[View at Publisher\]](#).
- [7] Gordon S,&PJ. London's \$8.5bn traffic jam slows down growth: The Financial Times; 13 October 2014.
- [8] Herman R&RBP. Single Lane Traffic Theory and Experiment Herman R, editor.: Elsevier Publications Co.; 1959. [\[View at Google Scholar\]](#); [\[View at Publisher\]](#).
- [9] Herman R. Technology, human interaction, and complexity: Reflections on vehicular traffic science. Operations Research. 1992 Apr;40(2):199-212. [\[View at Google Scholar\]](#); [\[View at Publisher\]](#).
- [10] Miller JS. A model to forecast peak spreading. Virginia Transportation Research Council (VTRC); 2012 Apr 1. [\[View at Google Scholar\]](#); [\[View at Publisher\]](#).
- [11] Helbing D. Traffic and related self-driven many-particle systems. Reviews of modern physics. 2001 Dec 7;73(4):1067. [\[View at Google Scholar\]](#); [\[View at Publisher\]](#).
- [12] Gazis DC. Traffic theory. Springer Science & Business Media; 2006 Apr 11. [\[View at Google Scholar\]](#); [\[View at Publisher\]](#).
- [13] Baykal-Gürsoy M, Xiao W, Ozbay K. Modeling traffic flow interrupted by incidents. European Journal of Operational Research. 2009 May 16;195(1):127-38. [\[View at Google Scholar\]](#); [\[View at Publisher\]](#).
- [14] Ardekani S, Ghandehari M, Nepal S. Macroscopic speed-flow models for characterization of freeway and managed lanes. Institutul Politehnic din Iasi. Buletinul. Sectia Constructii. Arhitectura. 2011;57(1):149. [\[View at Google Scholar\]](#); [\[View at Publisher\]](#).
- [15] Tignor SC WD. NCHRP 3-55(2)A: Roadway Geometric Design Criteria for Improved Safety and Operations at Intersections: Transportation Research Board; 2009. [\[View at Google Scholar\]](#); [\[View at Publisher\]](#).
- [16] (AASHTO) AAoSHaTO. A Policy on Geometric Design of Highways and Streets: AASHTO; 2009. [\[View at Publisher\]](#).
- [17] Planning FP, Handbook D. Florida Department of Transportation. University of North Carolina Highway Safety Research Center. USA. 1999;141. [\[View at Google Scholar\]](#); [\[View at Publisher\]](#).
- [18] Committee MoHSaS. Guidelines for Capacity of Urban Roads in Plain Areas New Delhi, India: Indian Road Congress; 1990. [\[View at Google Scholar\]](#); [\[View at Publisher\]](#).
- [19] Ethiopia FDRo. Ethiopia Road Authority Geometric Design Manual Addis Ababa, Ethiopia; 2013. [\[View at Publisher\]](#).
- [20] Turner SM,EWL,BRJ,&HDJ. Travel Time Data Collection Handbook Washington, D.C: Federal Highway Administration, Office of Highway Information Management, HPM-30; 1998. [\[View at Publisher\]](#).
- [21] Mannering FL, Washburn SS. Principles of highway engineering and traffic analysis. John Wiley & Sons; 2020 Jul 8. [\[View at Google Scholar\]](#); [\[View at Publisher\]](#).